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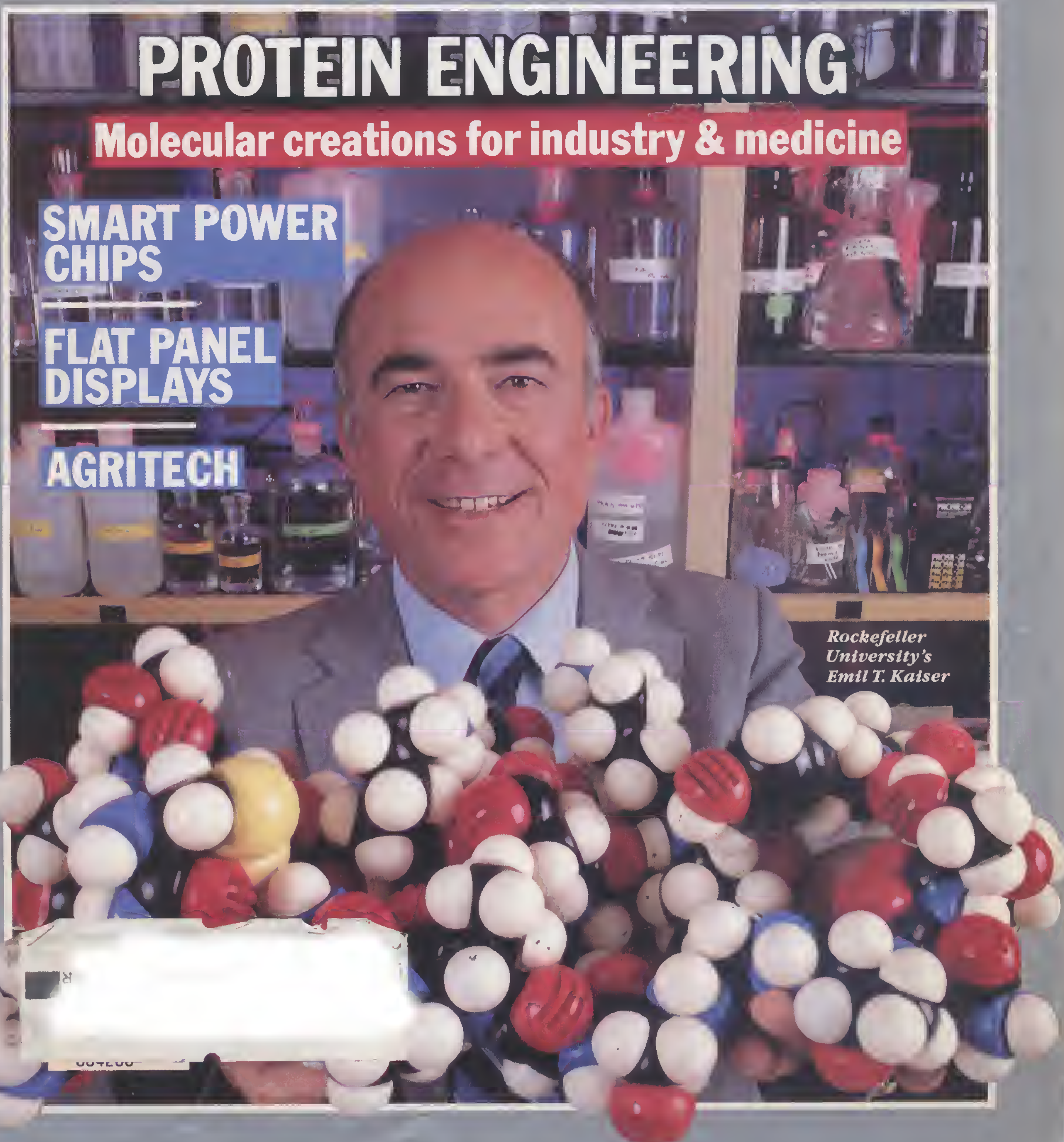

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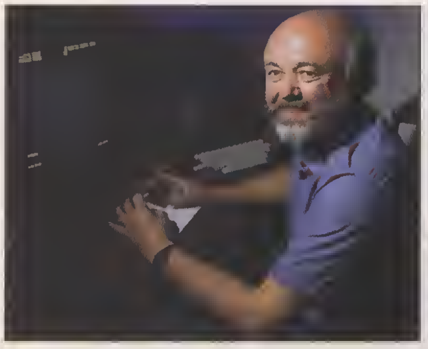

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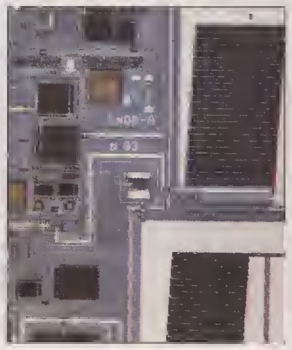

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Cover Rockefeller University's Emil Kaiser displays a model of his modified version of calcitonin, a calcium-regulating hormone; photograph by Ray Ellis.

OPINION

BOB DAHM

The price we pay for our military technology strategy: a brain drain

The United States has chosen to maintain military strength through advanced technology rather than through superiority in conventional weapons or troops. The Soviet Union, instead, has built up huge armies and naval forces equipped with large quantities of conventional weapons.

With either strategy, the cost is high. Both nations are hurting their economies by diverting material resources and millions of potentially productive workers to military pursuits. But the United States faces an additional problem: Many of its best technical and scientific minds are working exclusively on military projects.

There will surely be some commercial benefits from such efforts. Work in signal processors, space technology, body armor, optical computers, and other technologies developed for military use may someday lead to nonmilitary products. But the marketplace is not the goal of military R&D, and spinoff applications are strictly fortuitous. Also, reasonable cost is not a major objective in military systems, so the technology developed may prove uneconomical for commercial use.

Meanwhile, other nations can concentrate their brainpower on improving technology for industrial, business, and consumer products. As a result, they are gaining leadership in marketplace after marketplace, not just through cheap labor but also through superior manufacturing technology. For example, the Japanese are equipping factory complexes, at home and abroad, with optical fiber networks (HIGH TECHNOLOGY, Aug. 1985, p. 41). Robotics is spreading throughout Japanese industry, while in the U.S. it is confined largely to the automobile sector. Advanced steelmaking technology in other nations has helped foreign vendors take a large portion of the U.S. steel market away from domestic suppliers.

To meet these challenges, it's vital that many bright young engineers and scientists in the U.S. be attracted to work in basic industries—machinery, power generation, steel, textiles, chemicals, and so on. But the lure of military projects often proves irresistible: Military spenders are much more willing to go for far-out concepts and breakthrough attempts, and Uncle Sam pays better, to boot.

In the near term, U.S. manufacturers can remain competitive by providing higher pay scales and more freedom to explore innovative ideas. They can also pursue collaborative R&D projects in order to best use the available technical talent and resources, instead of continuing to duplicate each other's research; other countries, particularly Japan, already have many such large national collaborative R&D projects.

But in the long run, only reduced tensions and arms-reduction agreements can ensure competitiveness, by allowing the U.S. to shift its top talent into more useful enterprises.

Robert Haavind

Robert Haavind

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LETTERS

When nuclear consultants go overboard

If the local electric utility is trying to raise rates dramatically, a delayed or canceled nuclear power plant may be the culprit. Electric utilities with nuclear reactor projects have been hit hard with cost and schedule overruns, design errors, cancellations, and several dangerous accidents.

But one of the least-publicized causes of the failure of nuclear power is perhaps the most significant: the role of "independent consultants" hired by utilities to help them cope with the tangled net of stiff new regulations imposed in the 1960s and 1970s.

Plants were modified at the cost of hundreds of millions of dollars as a result of these "analyses." While many modifications were in fact needed, others were the unnecessary result of recommendations that bordered on the absurd.

Proposed modifications are based on "postulated events"—something that an engineer, on the basis of his or her experience and training, suggests might occur during an emergency. Some of these events are very reasonable possibilities, but others are created simply to make more work for the consultant. On one project I worked on, an engineer calculated that a metal light fixture would fall from the ceiling in an earthquake, make a 90° turn in midflight, somehow wend its way through a series of beams and columns, and then smash into a fire-hose reel, causing loss of firewater. Such a scenario set off a huge chain of bureaucratic procedures, ultimately concluding that there was no way that the light fixture could possibly hit the fire-hose reel. I have seen modifications where several cubic feet of solid steel were used to restrain a 1-inch-diameter pipe that was supposedly in danger of rupturing in an earthquake; the restraint was so massive that it would have stopped a Sherman tank.

The Seabrook project (N.H.) was proposed 13 years ago as a twin-reactor plant costing under $1 billion. Its owners now estimate that the single reactor slated for service in late 1986 will have cost $4.56 billion.

STEVE LISS

Who is responsible for the sloppy engineering and the cost and schedule overruns? You can't really blame the consultant, who is trying to please the client and stay in business. You can't really blame the utility, which is trying to get the plant on line as fast as possible. Ultimately, the blame rests with the federal agency that regulates the construction and operation of nuclear power plants—the U.S. Nuclear Regulatory Commission (NRC).

The NRC should pay for and oversee the activities of engineering consultants working on nuclear power projects. This would in fact make the consultant an independent analyst. Recommendations should be checked by the NRC to prevent oversights and absurd design modifications. These and other measures to improve nuclear engineering should be implemented now so that our children won't be facing payments for billions of dollars of errors, inefficiencies, and wasted efforts.

Nicholas M. Baran
San Francisco, Cal.

Data communications: more than hardware

The September article concerning telecommunications problems ("Making sense of the telecommunications circus," p. 20) is a well-structured and timely analysis of an industry in disarray. But hardware solutions (the article's focus) are only partially effective in cost cutting; someone somewhere has to design the actual data communications network.

Data communications users can now independently reconfigure their networks to meet changing needs and changing equipment, often precluding the necessity to turn over costly hardware. The cost savings that result from determining and specifying data communications links are a necessary partner to having access to state-of-the-art hardware.

After all, you still need to point your machine in the right direction.

Gary Shilling, Vice-President
System Engineering Tools
San Diego, Cal.

Diagnostics outside the hospital

I was most interested in the excellent article "Healthcare looks beyond the hospital," (Sept., p. 46), but I would like to point out an omission. The article failed to mention Miles Laboratories or its Ames Division, a pioneer and current leader in the field of self-testing and physician's office diagnostics. In 1941, Ames pioneered self-testing of urine by diabetics with its Clinitest tablets. Since then, we have developed numerous tests for abnormalities in both blood and urine, along with sophisticated instrumentation for use in hospitals, clinics, the physician's office, and the home.

Our Seralyzer reflectance photometer, for example, is a state-of-the-art diagnostic instrument that utilizes unique dry-phase chemistry to perform sophisticated blood chemistries and tests for electrolytes, enzymes, and routine analytes. It was introduced in 1982 and is currently the market leader.

I am sure that, as the article states, other companies will join the ranks of those already in diagnostics beyond the hospital.

Walter Wenninger, Exec. VP
Diagnostics Group
Miles Laboratories
Elkhart, Ind.

The building blocks of information

As an architect, I may seem to be a less than likely reader, but I find that the opportunity to keep abreast of recent developments as presented in HIGH TECHNOLOGY gives me advance information on technology that may affect building systems, material, and design. It also provides insights into the needs and aims of corporations active in various fields of technological development as potential clients for architectural and engineering design services.

Allen Trousdale
The Grad Partnership
Newark, N.J.

High Technology Month award

We are pleased to inform you that HIGH TECHNOLOGY magazine has been selected to receive the Congressional Science and Technology Award for promoting international understanding of technology ("Japan's technology agenda," Aug.). These awards, presented in conjunction with National High Tech Month, are given by the Congressional Caucus for Science and Technology in association with the Congressional Institute for Space, Science and Technology to salute outstanding public- and private-sector contributions in the areas of science, science policy, and innovative technological achievements that benefit society.

Mervyn M. Dymally, Member of Congress
Chairman, Congressional Caucus
for Science and Technology

We welcome comments from our readers. Please address letters to Editor, High Technology, 38 Commercial Wharf, Boston, MA 02110.

Speeding up image transmission

A new microcomputer peripheral cuts the time needed to send a video image over the telephone line from minutes to seconds. Real estate, advertising, and other businesses that rely heavily on pictures are expected to constitute the major market for the system, recently introduced by Widcom (Campbell, Cal.).

The roughly 1.2 million bits of data ordinarily needed to describe a color video image take about 20 minutes to transmit using a standard 1200-bit-per-second modem. Widcom's Rapics 500 speeds things up by encoding pictures with no more than a tenth that number of bits. The Rapics first analyzes the picture to yield a series of numbers (coefficients) that represent "spatial frequencies"; the lowest frequency signifies overall image brightness, and higher frequencies indicate edges and detail. To compress the data, the system discards unimportant coefficients—such as those corresponding to high frequencies in a mostly featureless image—and condenses the remaining coefficients by assigning fewer bits to values more likely to occur. For example, zero, which indicates that a frequency is absent, is assigned the shortest code.

This compression allows a computer connected to the Rapics to transmit most images in less than a minute with with no visible distortion, says Widcom VP and chief scientist John Douglas. The user can instruct the system to compress images to a fixed file size (say, 8 kilobytes) or to a specified degree of distortion. In addition to shortening transmission time, the $4500 Rapics can pack as many as 45 pictures on a floppy disk that has room for only two uncompressed images.

With Rapics, video image suffers little in compression from about 150K bytes (top) to under 8K bytes.

Graphite fiber gets a new twist

A Carnegie-Mellon University research group has developed a flexible graphite fiber that could lead to vastly improved composite materials. It could be combined with plastic to produce a material that is lighter, less brittle (and thus more impact-resistant in planes and cars), and more economical than existing graphite fiber composites.

In the new process, ordinary graphite fiber is reacted at high temperatures with an inorganic reagent that is halogenated (i.e., that contains a chemical such as chlorine, bromine, or fluorine). "It produces a much more flexible fiber that is only about half as dense as conventional fibers," says Deborah Chung, associate professor of metallurgical engineering and materials science at Carnegie-Mellon. "Because of its lighter weight, we also estimate that cost per unit volume could be reduced by 20% using this method." The fibers' flexibility, which will reduce breakage during production, will add to the economy factor, she says. A patent has been filed for the process, and Chung is now discussing commercialization prospects with a major chemical company.

Ordinary graphite fibers lend high strength to composites, but their use is sometimes limited by brittleness. Besides adding flexibility, the relatively low density of the new fibers means that more can be packed into a composite without adding excessive weight. The result is not only higher strength but also useful electrical properties. Damage to a plane struck by lightning would be decreased, for example, because the greater concentration of conductive fibers would diffuse the charge more efficiently.

UPDATE

Fighting oil spills with lasers

As newly discovered Arctic oilfields go into production over the next two years, the risk of a major spill will increase dramatically. The Canadian government is promoting an innovative scheme for combatting such spills: zapping them with helicopter-borne lasers. Unlike conventional remedies, this approach is well suited to the Arctic. Devices that skim oil from open seas do not work in ice-congested water. And simply burning the stray crude would be difficult, because the frigid surroundings tend to extinguish fire.

In the event of a spill, oil would surface in tens of thousands of puddles on the ice. One laser on the chopper would send down a steady infrared beam to heat the oil, making a vapor-rich zone above the puddle. A second laser would supply short, intense pulses to ignite the vapor. Tests in a simulated Arctic environment showed the lasers able to burn as much as 90% of the oil in a few seconds, says Harry Whittaker, head of environmental emergencies engineering at Canada's Environmental Protection Service.

Oil companies' present contingency plans call for dropping special flares on the oil. But laser mop-up should prove cheaper: A major spill would consume some $3 million worth of flares, says Whittaker, while the reusable laser system costs about $250,000.

Vaporized and sparked by lasers, a simulated oil spill goes up in flames.

Electronic glue for microprocessors

Microprocessors are becoming standard components in everything from autos to antitank guns. Unfortunately, connecting the microprocessor to the rest of the device requires special circuitry (often called glue) that is time-consuming and costly to develop. Now a group of former Zilog engineers have come up with the electronic equivalent of Elmer's Glue-all: an integrated circuit that can be quickly programmed with a microcomputer to make all the necessary connections.

The new device, a 100,000-transistor chip, has 64 logic blocks and 58 input/output blocks. The interconnections between the logic blocks can be rearranged electronically, as can the internal operations of the I/O blocks. Thus the logic cell array is rather like a printed circuit board with integrated circuits that can be changed instantly and metal interconnections that can be moved around at will. "It can take the place of conventional gate arrays or 15 to 75 small- and medium-scale integrated circuits," says Bernard Vonderschmitt, president of Xilinx (San Jose, Cal.), which manufactures the device.

The programs for setting up the array's logic and interconnections are designed with a Xilinx development system that runs on an IBM PC/AT equipped with a color monitor and a mouse. The programs are then downloaded to an EPROM (electronically programmable read-only memory), which sets up the array each time it is switched on. "Designing the logic circuitry is a matter of a few days," says Ross Freeman, Xilinx's VP of engineering and the creator of the logic cell array. "Changing a design is a matter of seconds, instead of weeks or even months for gate arrays."

LCDs: better contrast through chemistry

To solve the contrast and viewing-angle problems that plague liquid crystal displays, active-matrix LCDs take an electronic approach, using a semiconductor switch for each pixel. But two other new technologies, supertwisted and smectic LCDs, improve image quality simply by changing the display chemistry. Both of these passive designs are for large-area black-and-white displays.

In the supertwisted LCD, the liquid crystal molecule twists light 270° instead of 90°, improving polarization efficiency and roughly doubling the contrast and viewing angle. Smectic LCDs use a bistable ferroelectric crystal—a material that changes polarization as it shifts between two crystalline states—in an extremely thin sandwich. Power is necessary only for switching from one state to another. The contrast can be as high as 15:1 (versus 3:1 or lower in a conventional LCD), and the viewing angle is similarly improved.

For both technologies, developers are working to overcome drawbacks encountered in current prototypes. Supertwisted LCDs have slow response time, and smectic LCDs can't operate at high room temperatures.

All major LCD suppliers—Epson, Hitachi, Sharp, and Sanyo—are working on these technologies. Epson is focusing on smectic displays. It expects to have a commercial product in 12–18 months with a cost premium of about 20% over present LCDs.

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On the competitive status of U.S. industry

by N. Bruce Hannay
Chairman, Committee on Technology
and International Economic and Trade Issues
National Academy of Engineering

Is American industry becoming less competitive in international trade? The U.S. balance of trade, which we had come to take for granted, began to diminish over the past decade and then turned negative. Even trade in technology-intensive goods now reflects a shrinking U.S. share of world markets. And the rate of productivity improvement has fallen behind that of many other industrialized nations.

Do these trends reflect only an inevitable closing of the gap, as Europe and Japan rebuilt their industrial bases after World War II? Or are they signs of inherent weakness that could eventually undermine our preeminent world position and even bring a loss of leadership? (Our educational system, industry's management practices, government policy, and imbalances in exchange rates have all been blamed.) In order to begin answering these questions and addressing any underlying problems, the National Academy of Engineering (NAE) undertook a series of studies that examined central issues relating to technology and international trade.

The NAE's first major study, in 1976, was a broad examination of the relationship between technology, trade, and U.S. competitiveness. Its main conclusion was that our national performance with respect to technological innovation, productivity improvement, and competitiveness in world trade was primarily determined by the health of the domestic economy and the constraints on it, rather than by events outside the United States. Following up on this study, the NAE examined the effects of federal tax policy, regulation, and antitrust policy on technological innovation. But the conclusions reached in these studies were largely generalizations for industry as a whole; surprisingly little research had been done on government policies relating to technology and trade for specific industries.

Thus in 1979 we embarked on a series of industry sector studies, choosing seven industries—automobiles, electronics, pharmaceuticals, machine tools, steel, commercial aircraft, and fibers, textiles, and apparel—that represented a broad spectrum of characteristics. Our aim was to identify global shifts in production and trade, to relate such shifts to technological and other factors, and to assess the probable impact of public policy options on the international competitiveness of U.S. industry.

A number of similarities emerged from these seven studies. The most dramatic common theme was that despite differences among the industries, all must now be termed world-scale. They must be managed in that context, and U.S. public policy must reflect the reality of mounting international competition. At present, however, relationships with other economies simply are not accorded the same importance in the U.S. as in Japan and western Europe.

A second common theme—not unrelated to the first—was the lack of coherence and mutual reinforcement among U.S. policies and institutions, and a lack of consistency in setting priorities. This is in stark contrast to the situation in Japan.

Other common themes included the handicap of small firms in pursuing international sales, disadvantages in the cost and availability of capital and in the projected rate of return on investment, the growing importance of developing countries, the shortages of trained people at various levels from shop floor to management, and the requirement for large, well-funded R&D programs for producing the new technology that is constantly needed to maintain competitive advantage.

Although the industry-specific NAE studies identified several problems common to all seven sectors, forging effective solutions across the board will be no simple task. No two industries are alike in their patterns of technological development, in the problems they must solve in order to remain competitive in international markets, and in the public policies that would help them achieve these ends. Despite the differences, however, we arrived at some general conclusions about desirable policy actions.

The first conclusion is that government policy must be based on a substantially more informed view of the characteristics, needs, and prospects of individual industries. The studies showed that there are opportunities for policies aimed at specific industries—for example, changes in regulation in pharmaceuticals, support for exports by small machine-tool manufacturers, and steps to lower the cost of capital for steel and electronics—that would improve the competitive position of U.S. industry in the international marketplace.

This implies the need for a continuing and coordinated review of technology and trade issues at a high enough level in the government so that timely, effective action can be taken. While our system of government and our limited understanding of the dynamics of the economy do not permit us to adopt a fully articulated "industrial policy" in the foreseeable future, it is clear that better coordination among the many separate policies and policymakers of our government is called for.

A second general conclusion from

This article is adapted from a report by the National Academy of Engineering, "The competitive status of U.S. industry—an overview," released last May. The author would like to thank Lowell Steele for his valuable contributions to the NAE studies.

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the studies is that there is a challenge to U.S. management and labor. We have no monopoly on competence, foresight, or competitive drive. Preexisting factors, such as a giant domestic market, plentiful national resources, an educated work force, political stability, and private enterprise, have historically contributed to our successes, but they may also have delayed recognition of our weaknesses. We must now pay increased attention to world markets, to foreign competition, to foreign policies on trade and technology, and to foreign managerial innovation. As a corollary, we also need increased public support for education in foreign languages and foreign cultures, as well as more rigorous standards for public literacy in science and technology.

A third general conclusion is that the government needs to give sustained attention to the problems faced by small companies, which often need special help to compete in foreign markets. In particular, small companies generally lack the expertise to deal successfully with foreign regulations, procedures, and market systems. Until recently, the financial assistance available from Eximbank was unavailable to smaller companies or for smaller transactions in all companies.

Finally, we concluded that the problems identified are amenable to solution within the context of our systems and values. We are not suffering some inexorable decline. We do not lack the critical resources—natural, human, or technological—needed for an effective response, and our sociopolitical institutions are flexible and adaptable. Improvements in policy and in administration will depend on two things: a broad awareness of changing international circumstances and a consequent change in priorities for responding to the new international environment.

Certainly some of the gains Japan and Europe have made in relation to the United States were part of an inevitable readjustment. At the same time, we are no longer complacent; we recognize our previous lack of attention to many of the key ingredients of modern economic vitality. This recognition has led us to consider various remedial policies and actions, and even to adopt some of them—although we still have a long way to go. We need a continuing flow of new technology, as well as policies that encourage development and use of this technology, if we are to remain the world's economic leader. □


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BUSINESS STRATEGIES

Commodore:

CAN THE AMIGA SPARK A TURNAROUND?

With more than $80 million at stake, Commodore International (West Chester, Pa.) is gambling that its new Amiga personal computer, a radical departure from its far simpler line of home computers, will rescue the company from the brink of financial ruin. The Amiga, which reportedly cost $40 million to develop and will require at least that much to promote, has drawn praise from analysts, users, and dealers alike for features such as sophisticated color graphics, stereo sound synthesis, high-speed processing, and IBM PC compatibility. Initial reviews were so glowing that some computer buffs placed their orders even before the machine was shipped in September. Yet skepticism abounds, even among the Amiga's champions, about its chance of success.

"I'd like to give Commodore the credit it deserves for having the guts to come out with a new technology," says Jay Rosovsky, president of Computone Systems (Atlanta), which may carry the Amiga in its Future Information Systems chain of computer retailers before Christmas. "There's been nothing new since [Apple Computer's] Macintosh." But Rosovsky concedes that selling the Amiga will be tough, considering how dramatically the home computer market has cooled in the last year. "It's a case of terrific technology that will be difficult to get moving," he says.

Until as recently as 1984, Commodore was riding the crest of the home computer boom. The popularity of its Commodore 64 propelled the company's sales to $1.2 billion in the year ending in June 1984—almost double the $681 million total for the previous year. But by last Christmas, the firm had saturated the market with the 64, and sales of its two new computers, the Plus 4 and Plus 16, never took off.

Most analysts believe management made a strategic error with the Plus 4. In what turned out to be an overestimate of consumer demand for built-in software, product designers gave the machine built-in word processing, database management, and spreadsheet programs. Amid howls of protest from the public, the company left out the sound and graphics capabilities that had made the Commodore 64 so popular. As a final blow, the Plus 4 couldn't even run Commodore 64 software, which was flooding dealer shelves at the time.

Commodore's misreading of the market left it—and retailers—with full warehouses last Christmas, and the $450 million in inventory quickly drove the company into red ink and layoffs. For the quarter ended June 30, the company lost $124 million, $63 million of which came from writing off unmoved inventory. Now, according to Robert B. Trukenbrod, vice-president of marketing, the company is trying to fight its way back with two new machines: the Amiga and a long-awaited upgrade to the 64, the Commodore 128. The 128 became available about the same time as the Amiga, but hasn't managed to generate the same excitement, especially among software developers.

Despite the Amiga's splashy debut, dealers and analysts are concerned about its market focus. At a suggested list price of $1295 for the basic unit without a monitor, the machine is at the extreme high end of the home market. In contrast, the company's Commodore 64 and VIC 20 computers sold for $500 or less. Many of the Amiga's technical features seem to be aimed more at business applications than home users. It uses a Motorola 68000 processor and two proprietary chips for high-speed data processing and can do several tasks simultaneously, displaying them in progress in several screen "windows." This feature allows users to continue using a word-processing program, for example, while the computer is sorting addresses and printing envelope labels.

But the machine has so far made little progress in the business market. Very few established software developers have shown interest in writing Amiga business programs, even though the machine's designers took pains to make it accessible to independent developers of software and accessories. The basic computer comes with one 3½-inch floppy disk drive, an 89-key keyboard, and 256K bytes of internal random-access memory. The computer's memory can be increased to 512K bytes with an optional plug-in cartridge. In an effort to gain access to the vast store of current business programs, Commodore is producing software that it says will allow the Amiga to run IBM PC programs; however, IBM software doesn't take advantage of the Amiga's sophisticated graphics.

Although the machine's basic price is relatively low for business PCs, users can't benefit from many of the machine's capabilities without adding expensive accessories. The Amiga can be hooked up to a television or an ordinary PC video monitor, but its own $500 monitor is necessary to obtain a display adequate for business applications. A second disk drive—almost a necessity on a computer with the Amiga's power—costs $295. And to run IBM PC software, the owner has to buy a 5¼-inch disk drive at $395 in addition to the conversion software (expected to run about $200).

But for small dealers who are having a tough time surviving the sales drought of the past year, the Amiga looks like a good deal, says Bob Special, owner of the C64 Store (Smyrna, Ga.). Dealers get 40% commissions and the potential of selling a variety of accessories and software. When the Amiga was shipped in September, Commodore had signed up 662 dealers—although the large chains were notably absent from the list.

SAL DIMARCO

Commodore hopes to ship 50,000–100,000 Amigas by year's end, says Robert B. Trukenbrod, VP of marketing.

In recruiting dealers, however, Commodore keeps coming up against past history, including charges that at one time it gave such deep discounts to catalog showrooms and discount chains that some dealers could buy a Commodore 64 for less at K Mart than they could from the factory. Commodore staunchly maintains that won't happen with the Amiga and claims it will offer no volume discounts on the machine. VP Trukenbrod says that the company also intends to improve on its previous service record and has a program already in place to deal with the inevitable software bugs that exist in new computers. He says the company is trying hard to build a dealership network that will last, because its plans for the future are only beginning to unfold. "The Amiga," says Trukenbrod, "is just the first of a number of new products from Commodore." ***—Robert Snowdon Jones***

Environmental Technology:

FROM POLLUTION CONTROL TO PLATINUM MINING

Environmental Technology president Mark Wemhoff is prospecting for platinum with a modified version of the firm's hazardous-waste processor.

In an uninhabited area near Fallon, Nev., scientists from three-year-old Environmental Technology (Orlando, Fla.), a maker of automated systems for treating hazardous industrial waste water, are planning to "mine" platinum from underground stores of water. The platinum extraction apparatus is a modified version of the small company's original product, a compact, computerized system that can separate as many as 30 different metals from waste water. The company already has successfully extracted platinum in the lab from geological waters and is in the midst of a six-month field test in the Carson Sink region of the Nevada desert.

Environmental Technology president Mark Wemhoff predicts that, if all goes well, the company will be able to extract as much as 20,000 ounces of the precious metal a year. With the Soviet Union and South Africa now supplying most of the platinum used in the U.S., the company and its backers reason that a domestic supplier could readily capture a chunk of the 2-million-ounce annual market, especially for strategically sensitive applications like weapons guidance systems, electronic equipment, and jet engines. The privately owned firm has raised $2 million for the project, most of it from American Aquatech International (Vancouver, B.C.).

Environmental Technology's original product, the automated hazardous-waste processor, was developed as part of an earlier $5 million R&D program. About the size of a hotel ice-making machine, the CPU-4000 sells for $75,000 and costs another $25,000 to install. It can treat up to 1000 gallons of waste water an hour, says the company, making it appropriate for use in such industries as electronic component manufacturing, electroplating, and commercial printing, as well as for firms that develop x-ray and photographic film. Since the system went on the market in January 1984, Sperry, McDonnell Douglas, and a number of small circuit-board manufacturers have purchased units. Revenues in 1984 exceeded $1 million and are projected to at least double in 1985.

"The most appealing part of the system is the automation," says William T. Lorenz, president of William T. Lorenz and Co., a New Hampshire management consulting firm that follows the pollution-control industry. "In our surveys and market research over the years, we find that people want a system they can spend as little time with as possible." He predicts that the CPU-4000 and similar systems that will inevitably appear from competitors are the wave of the future for hazardous-waste handling. In part to stem such competition, the company is putting the finishing touches on a new, less expensive version of the CPU-4000 that is expected to sell for $50,000–$60,000, including installation.

Environmental Technology's Wemhoff claims that the CPU-4000's automation minimizes human contact with hazardous wastes and also eliminates the need for specially trained operators. Run by a programmable microprocessor made by Square D, the system automatically transfers measured amounts of waste from a company's storage tanks or directly from process waste lines to a chemical reaction tank. There, waste water is first neutralized. Then, separating and precipitating chemicals—a sodium sulfide-based reagent incorporating a polyelectrostatic flocculant (a substance that causes suspended particles to adhere to each other)—are added. These combine with metals in the solution to form nontoxic metallic compounds of valuable elements like silver, from which a submicron-level filter separates solids. For each 10,000 gallons of waste water, the CPU-4000 also generates 3½ gallons of sludge, which can be shipped in airtight containers to federally approved landfills for hazardous waste.

From a marketing standpoint, however, "there are some unique problems in pollution control," concedes Dan Bracewell, director of product development. "It's hard to get people to admit there's pollution in their plant until somebody's knocking on the door." To remedy the situation, he says, a company is often faced with having to buy "an expensive piece of equipment that doesn't add anything to the bottom line." After grappling with this difficult market, Environmental Technology's 17 employees are breathing a sigh of relief over the platinum recovery project.

If the platinum project proves successful, that doesn't mean the company will abandon the pollution control market, but it's easy to see why the prospect of producing precious metals holds more allure. High tech prospectors aren't all that different from the old-fashioned type, Wemhoff muses. "We find ourselves in a position much like the guys with the picks and shovels were in during the California gold rush." ***—Elizabeth Willson***

A new look at

Summary:

GTE lighting research operates on many fronts: a space lighting lab to study the motion of gases in a gravity-free environment; the use of various isotopes to enhance the output of fluorescent lamps; the production of light directly from excited molecules.

The science of lights and lighting might seem to be rather mature. Indeed, the standard light bulb has changed very little in at least half a century.

But lighting science is on the brink of revolution. Recent work by GTE points the way to major improvements in every type of lighting.

Lighting research in space.

One of the most powerful and efficient light sources is the high-intensity-discharge (HID) lamp. Its light is derived from gases and ionized vapors which are excited in an electrical arc contained in a quartz arc tube.

The gases circulate by gravity-induced convection, which mixes the radiating species in the arc. This tends to obscure other vital processes such as diffusion, cataphoresis (motion of ions toward the negative electrode), magnetostriction and vapor condensation. Researchers have wanted to observe these processes at leisure, in the absence of convection, for many years.

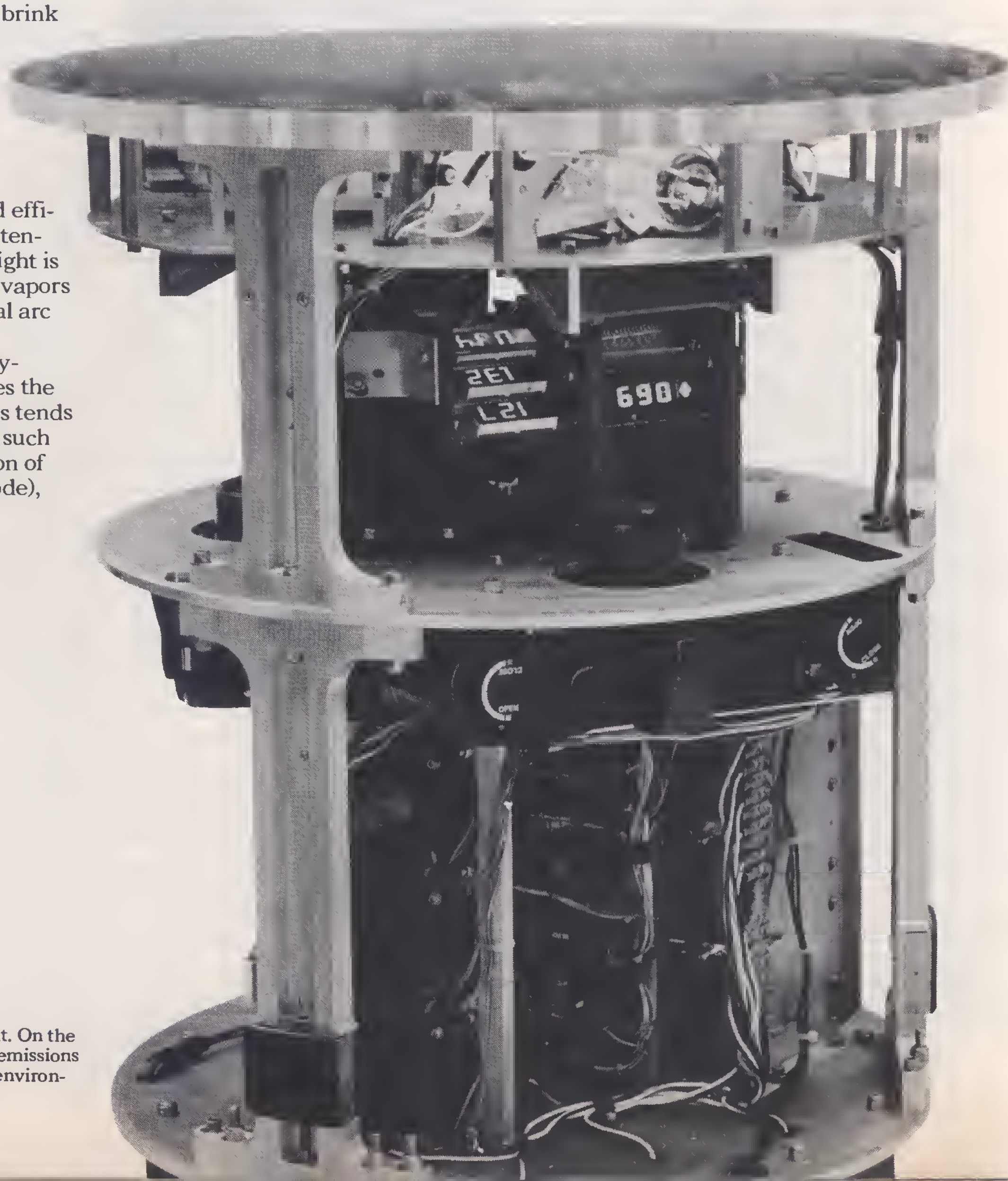
GTE has achieved this goal in a first-of-a-kind experiment aboard the space shuttle. A payload of three metal-halide HID lamps was operated in the microgravity environment of the orbiter. Each lamp was lit for half-hour periods while detailed spectroscopic, light output and electrical measurements were taken.

The results have substantially strengthened the technological underpinning drawn upon for lamp design. GTE scientists now have critical information and new insights that will produce lamps with brighter, whiter light.

Untrapping excited atoms.

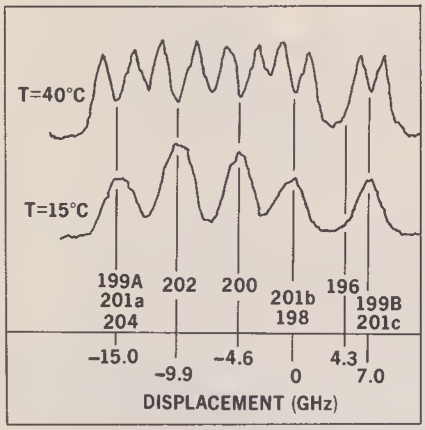
Improvements in fluorescent lamps are on the way, too. As just one example, GTE has discovered how to increase the efficiency of these lamps by about 5%.

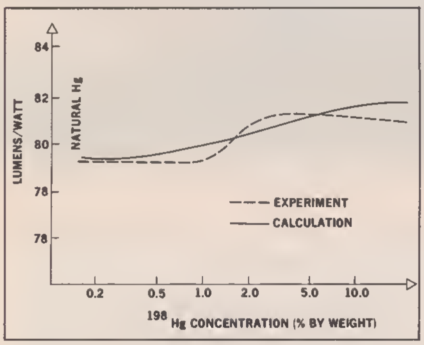
Mercury vapor in the lamp emits



Payload for the GTE space experiment. On the top layer are three HID lamps, whose emissions were investigated in the microgravity environment of the space shuttle.

an old science.





ultraviolet light when it is excited by the electric current. This light is transformed into white when it strikes the phosphors coating the glass tube but some ultraviolet is reabsorbed by the mercury vapor, limiting the lamp's efficiency. GTE researchers have found, however, that by increasing the level of 196 Hg isotope from its naturally-occurring 0.15% to 3.0%, more ultraviolet light escapes to the phosphor. Output improves about 5%.

Light from molecules?

In the future, light may be produced directly from excited molecules in low-pressure lamps. The light spectrum is in broad bands, rather than the narrow-line emission from mercury or sodium atoms.

GTE researchers are investigating ways to produce white light from molecules as the basis for a totally new lamp.

The chemical make-up of the molecules and their behavior in the excited state are undergoing critical studies. In many cases, GTE is applying electrodeless technology with RF power sources as exciters.

This new way of looking at light bulbs promises high-efficiency, long-lived, cool-running light sources with many industrial and residential applications.

The wonderful world of light.

At GTE, we are working on many projects aimed at bringing about the revolution in light. New electrode materials, improved sealants, excimers—these and more are on the GTE research agenda.

The box lists some current papers pertinent to GTE lighting research. For any or all of these, you are invited to write GTE Marketing Services Center, Department TP-L, 70 Empire Drive, West Seneca, NY 14224. Or call 1-800-828-7280 (in N.Y. State 1-800-462-1075).

Pertinent Papers

Convection and Additive Segregation in Metal-Halide Lamp Arcs: Results from a Space Shuttle Experiment
Symposium on Science and Technology of High Temperature Light Sources, Electrochemical Society Meeting, Toronto, 1985

Arc Discharge Convection Studies: A Space Shuttle Experiment
Proceedings of a symposium held at NASA Goddard Space Flight Center, Greenbelt, Maryland, August 1-2, 1984

Energy Conservation Through More Efficient Lighting
Science, Volume 226, pp. 435-436, October 26, 1984

Enhanced HgBr emission at low pressures
Applied Physics Letter 42, May 1, 1983

Bound-free emission in HgBr
Applied Physics Letter 41, November 1, 1982

GTE

SMART POWER

Chips that combine electronic intelligence with electrical brawn can make equipment smaller and more efficient

by Herb Brody

A new class of electronic chips is coming on the scene to bridge the gap between the disparate worlds of electrical power and electronics. These "smart power" devices, on which low-voltage signals control high voltages and currents, could reduce the size and cost, and increase the reliability, of any system where electrical equipment is put under computer command. Automobiles and automated factories could shed much of their trouble-prone wiring, computers and other electronic equipment could be made more compact, and consumer appliances such as refrigerators and air conditioners could become more efficient. So far, however, smart power has remained more a buzzword than a commercial reality.

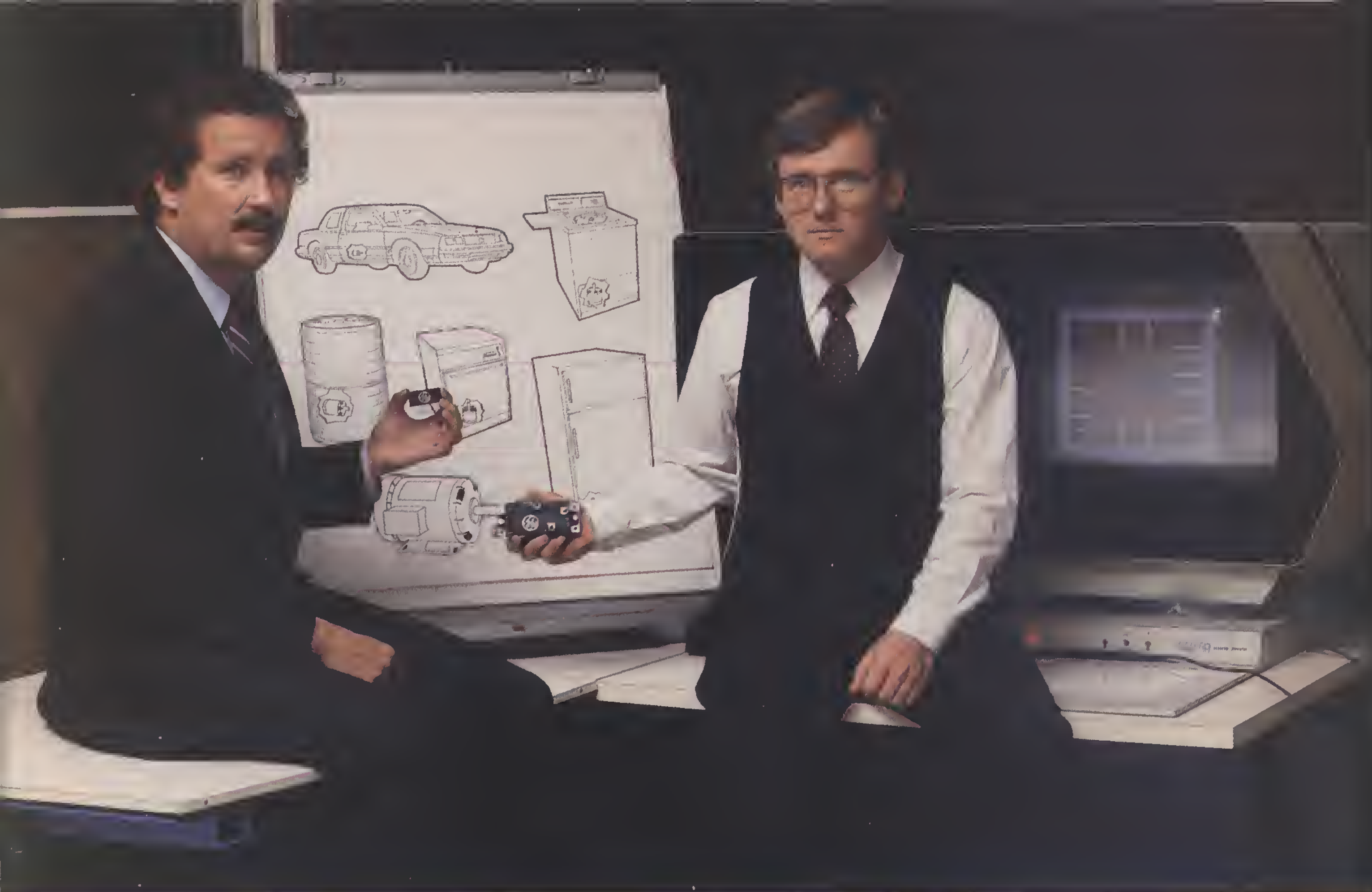
The lure of smart power has hooked companies ranging from start-ups to established semiconductor manufacturers like Motorola and Texas Instruments. General Electric has mounted a massive effort in the technology, which the company expects will constitute a $1 billion market in the mid-'90s (up from about $50 million in 1984). "This is a revolutionary way to apply power," says J. Larry Smart, general manager of GE's power electronics semiconductor department (Syracuse, N.Y.). "These devices let you leverage more features into a product at less cost." GE's development of smart power devices was its second largest R&D program last year, according to Smart, topped only by a project to develop a new jet engine. "Smart power is to power electronics what the microprocessor was to signal electronics," he says.

Such analogies come up often in discussions of smart power. Microprocessors, as well as simpler chips, "do nothing that could not have previously been done with big piles of transistors," says Michael S. Adler, director of the power electronics laboratory at GE R&D labs (Schenectady, N.Y.). Similarly, "you're not doing anything with smart power that you can't do with lots of discrete components." The difference, he says, is that "now certain applications will become cost-effective, size-effective, and weight-effective" because a handful of smart power chips can replace hundreds of separate components—several printed circuit boards full.

The principal advantages of integration are the potential for lower cost because of the smaller amount of silicon, and higher reliability due to the smaller number of parts and connections. Such advantages remain largely theoretical, however; smart power chips are now being made only in small quantities and are often several times as expensive as an equivalent circuit of discrete components.

Advances in several semiconductor technologies underlie the development of smart power. Of key importance was the advent in the late '70s and early '80s of a type of transistor that could control large electrical currents while drawing very little current itself. Consisting of three layers—metal, oxide, and semiconductor—these "MOS-gated" transistors are switched on and off with the application of a low voltage; they are therefore amenable to integration with electronic signal circuits, which typically produce a small voltage and very little current. Until MOS technology emerged, the bipolar transistors used to control high currents required a substantial current input.

A crucial requirement for smart power is the ability to put low-voltage and high-voltage components on the same silicon chip. Microprocessors and other "intelligent" electronic devices operate with low voltages, typically 5 volts. But electrical equipment like motors and lights usually run off the 110- or 220-V ac power line. In addition, there are a growing number of electronic systems that demand several hundred volts; examples include electroluminescent flat panel displays and nonimpact printers. The most compact way to apply smart



GE's J. Larry Smart (left) and Thomas Daly expect a $1 billion market for smart power, much of it for cars, electric motors, and appliances. Smart power's impact will rival that of the microprocessor, Smart predicts.

control to these loads is to put low-voltage elements like logic gates on the same chip as the switches that govern transmission of the higher voltages.

Unless special measures are taken, however, the high voltage coursing through the "power" part of the chip will interfere with the delicate low-voltage operations on the "smart" side. The most common techniques for keeping high and low voltages in their place are junction isolation and dielectric isolation. In junction isolation, p- and n-type semiconductors are juxtaposed on the chip at strategic points; as long as it receives a high enough bias voltage, the p–n junction conducts current in only one direction and so acts as an electrical barrier. GE now markets a junction-isolated IC that can take a 5-volt signal input from, say, a microprocessor and use it to control an output of up to 500 volts.

Dielectric isolation requires a silicon wafer on which a thin layer of silicon dioxide has been grown. Crystalline silicon is deposited in "tubs" on top of the oxide; circuit elements are kept at an electrical distance from each other by the surrounding area of nonconducting, or dielectric, oxide. Although dielectric isolation is somewhat more effective than junction isolation, the oxide-coated wafers are expensive, and the devices require nonstandard fabrication steps that limit the utility of this technique.

The need to carry high currents, as well as high voltage, is one of the biggest challenges for smart power technology. Ordinarily, increases in current must be accompanied by increases in chip area. A way around this is to arrange the device so that the current flows "vertically"—that is, entering the top of the chip and exiting through the bottom; vertical flow allows a much smaller chip area for a given current than does lateral flow, in which charge moves sideways within a single layer of silicon.

Lateral flow, however, is standard for logic and control ICs such as those based on CMOS (complementary metal oxide semiconductor—a technology that yields fast, very low-power devices). Integration of CMOS logic with vertical MOS power on one chip is difficult, and usually the power transistor is removed to a separate piece of silicon. The result is a hybrid that, while no longer matching the strict definition of smart power as one-chip integration of power and control, still reduces to two chips what might otherwise take dozens.

One product that became feasible only with the advent of smart power is the electroluminescent (EL) flat panel display (see "Electroluminescence," p. 42). An EL panel needs several hundred volts to light up. This voltage is supplied by a grid of electrodes in response to the much lower voltages generated by a keyboard or a computer memory. A horizontal electrode carries about 200 V to an entire row at a time; then column electrodes are pulsed with a smaller voltage (40–90 V) to produce a glow at the intersection. Before the advent of high-voltage ICs, this task required a 19-inch rack containing over 700 discrete components, says Christopher N. King, executive vice-president of Planar Systems (Beaverton, Ore.), the major U.S. maker of EL displays. "This is hardly appropriate when your whole pitch is thin-ness," he says.

Now, a single printed circuit board can hold all the smart power chips needed to operate an EL display. "The

market for smart power display drivers will explode—as soon as we get our costs down," says William Numann, marketing manager for power integrated circuits at Siliconix (Santa Clara, Cal.). Siliconix is not alone in bidding for the display driver market; competitors include Texas Instruments (Dallas) and Supertex (Sunnyvale, Cal.). In addition to EL panels, which most analysts expect will gain rapidly on liquid crystal displays in the coming decade, smart power will be needed for plasma displays and perhaps for smectic LCDs—a new high-contrast display technology that requires higher voltages than those now common for today's twisted-nematic LCDs. .

Selling a new chip technology within the electronics industry is one thing; convincing engineers in other, more conservative industries may prove a more difficult task. But it is there—where electronic signals must direct electrical might—that smart power has its greatest potential.

Every time some bright auto engineer adds another automatic electric feature to a car, a new wire must be added connecting the load (say, a motor or light) to a switch on the dashboard or the door, and to the battery. As a result, "the wiring harness is getting to be wrist thick," says Jim Siegel, marketing manager at Ford Motor's electrical and electronics division (Dearborn, Mich.). "It's hard to bend and therefore hard to install. And its size and weight are especially troublesome as we go to downsizing and aim for aerodynamic design."

With smart power, not only could the wiring harness be made much smaller, lighter, and more flexible, but inherently unreliable electromechanical relays would be replaced by solid-state devices. There is consensus in Detroit that this new approach to wiring will come, probably sometime in the 1990s, even though no cars now in production use it.

In the proposed scheme, the act of flipping a switch would not directly close a circuit; instead, it would send a digital signal through a thin communications wire loop that hooked up to a smart power device at each load. The signal would be encoded with a message such as "headlights, turn on." Control circuitry on a smart power chip at the headlights would decode the signal; this circuitry would trigger an on-chip transistor to begin passing current from an incoming power cable to the lamp filament. The chips at other loads would recognize the signals as not being for them and would not switch.

In principle, this approach would require only two wires to serve the entire car: the thin, low-voltage signal wire and a single power cable. If fully implemented, such a "multiplexed" wiring system would take about 25 pounds of copper out of a car. Smart power multiplexing will first appear in Ford cars in about two years, says Leonard J. Groszek, technical planning manager for the automaker's electrical and electronics division; a fully multiplexed car will probably arrive in five or ten years. GM seems to be following a roughly similar timetable. "I would expect a significant increase in multiplexing in the 1989 model year," says Edward G. Whitaker, an engineering manager at GM's Delco Electronics division (Kokomo, Ind.). "There are 52 wires leading into the door of a Cadillac," he says. "We want to reduce that to three: control, power, and ground."

Besides reducing an electrical system's bulk, smart power could add diagnostic capabilities. After receiving a signal to turn on, the chip could put a message on the signal wire confirming that it had done so, permitting a dashboard status display of all the car's lights, electric windows, and so on. Since the smart power device could easily sense whether current was actually flowing to the load, it would detect and report a burned-out lamp (or a stuck power window) via the signal wire. Such functions are certainly possible with discrete components, but "an integrated smart power chip could do what now takes 10 discrete components," says Whitaker. He estimates that future GM cars will use 20–30 smart power devices each.

Obstacles remain, however. The biggest one is that smart power devices are not yet available on the cheap and plentiful basis that automakers are comfortable with. "It's a potentially huge market, with perhaps hundreds of devices per car," says Groszek. "We need large quantities of 50¢ devices, versus the present limited quantities at several dollars apiece. The semiconductor industry has talked about making millions of these devices a week, but nobody's doing it yet. There's still a lot of work to be done."

A similar multiplexed wiring idea using smart power has turned up in a factory communications system recently introduced by GE's Automation Controls Department (Charlottesville, Va.). In many of today's automated factories, cables radiate octopus-style from a central computer to the various machine tools, robots, and material-handling conveyors under its command. With GE's system, a single power cable and a single signal wire run to each computer-controlled machine. There, a module containing a smart power chip receives instructions from the computer to turn on or off or to change speed. The chip decodes the instruction and feeds the appropriate drive voltage into a power transistor that controls the electrical power to the machine.

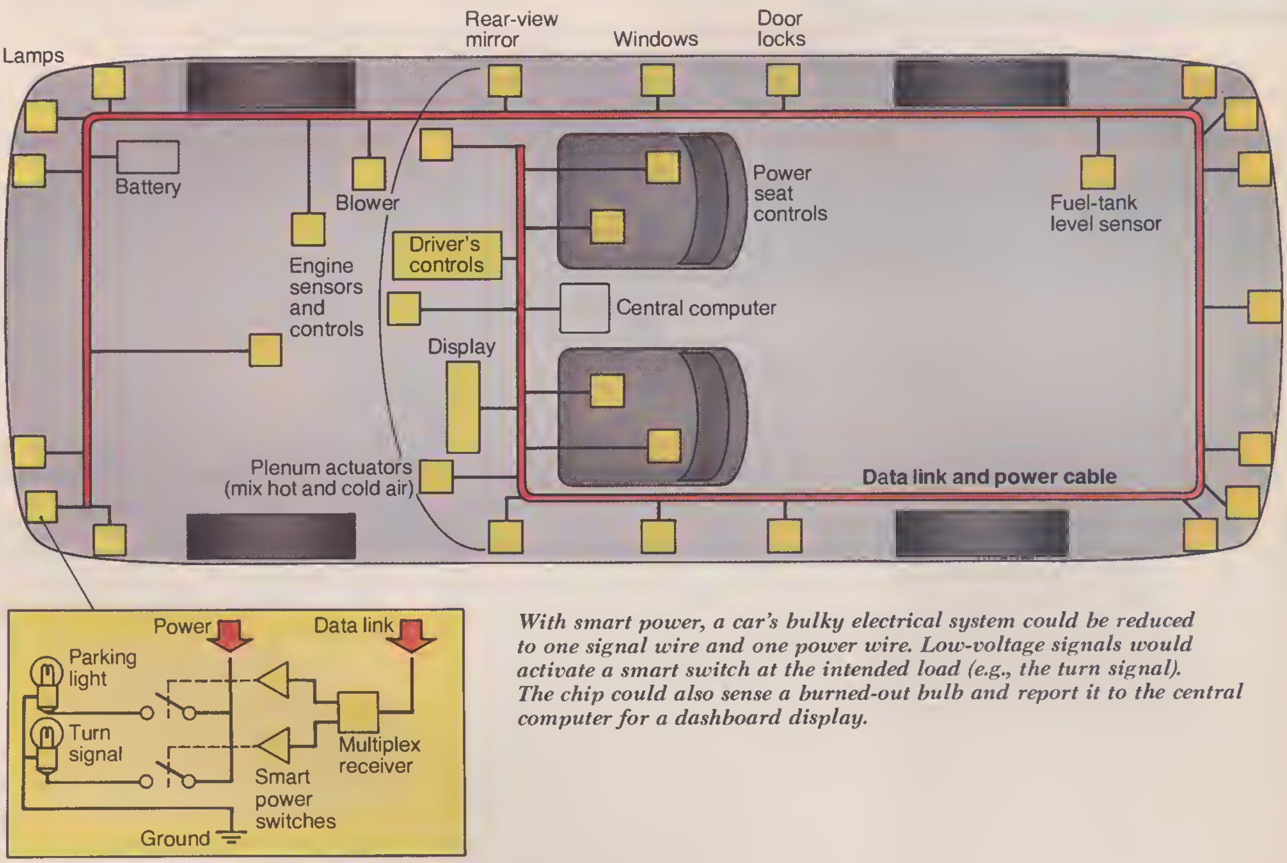
As in a multiplexed car, these smart power switches provide a handy way to monitor whether a machine is functioning properly. The chips continuously sense current and voltage and transmit the readings to the computer; too much current or voltage indicates a short circuit or some other system fault and prompts the computer to issue a command to shut down that piece of equipment—rather than blowing a fuse or circuit breaker that would interrupt several machines. GE claims the system should decrease downtime by 50%.

In cars and factories—as well as in many consumer products—the load that is being controlled is often an electric motor. Indeed, an estimated 60–70% of the electricity generated in the U.S. is consumed by motors. Much of that power is wasted. Often the inefficiency stems from the inability to vary the speed of the motor. A smart power motor controller permits precise, continuous speed variation and hence could provide vast energy savings.

Without smart power, there are two main ways of getting variable output from a motor. One is to use a direct-current (dc) motor, which lends itself readily to variable speed. But dc motors are expensive and unreliable; the carbon brushes they require to induce a magnetic field in the rotating element (rotor) are easily damaged. The other approach is to take the fixed-speed output of an alternating-current (ac) motor and adjust it externally, as with gears or (for an air blower) baffles. However, while ac motors are relatively cheap, these additional components reduce efficiency and reliability and add cost, and in any case do not provide precise and continuous control. A new class of motors under development could use smart power to attain variable speed without the need for a dc motor's troublesome brushes or an ac motor's inefficient add-ons.

These "electronically commutated motors" (ECMs) work by switching power on and off to the motor windings to create a series of pulses whose timing and duration govern the motor's speed. (A motor working directly off ac power will spin at a rate that is some multiple of the fixed 60-hertz line frequency.) With smart power, the action of these power switches—and hence the motor's speed—can be tied to some externally sensed variable, such as temperature. "It's now possible for motor speed to be varied as a *function* of something," says William J. Ehner, general manager of the technology department at GE's mo-

Multiplexed car



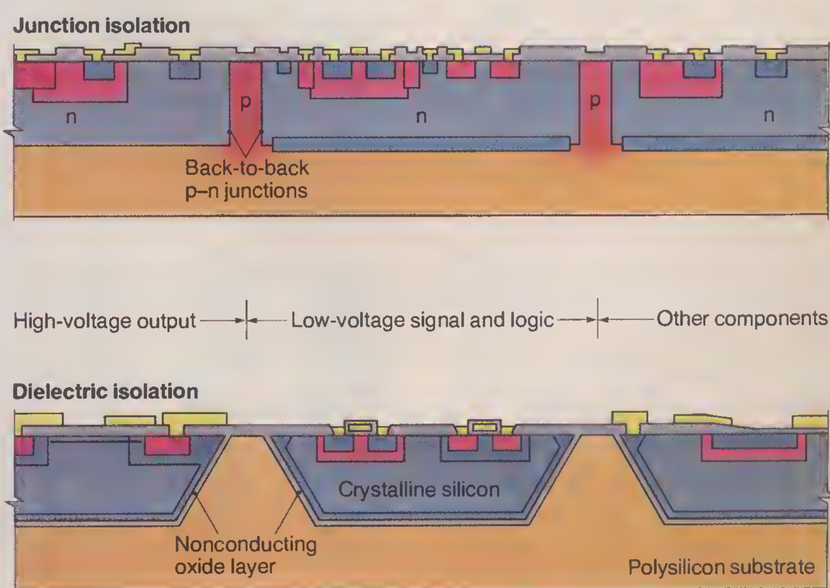
With smart power, a car's bulky electrical system could be reduced to one signal wire and one power wire. Low-voltage signals would activate a smart switch at the intended load (e.g., the turn signal). The chip could also sense a burned-out bulb and report it to the central computer for a dashboard display.

ILLUSTRATED BY MARK E. ALSOP

GE

This junction-isolated chip, rated at 500 volts, could replace the assemblage of discrete components shown.

Isolating voltages



Peaceful coexistence between high-voltage and low-voltage circuit elements on the same chip is crucial to smart power. An electrical barrier can be formed by diodelike junctions (top) or by an insulating layer (bottom).

BUSINESS OUTLOOK

Smart power chips may spark big markets

Sales of smart power devices—integrated circuits that combine logic and electric power controls on a single chip—are currently quite small compared to the billion-dollar market for discrete power transistors. At $10–$20 per chip, smart power ICs are relatively expensive. But electrical systems under the control of these chips are lighter and less bulky, and are potentially more reliable and more efficient than systems using assemblies of discrete power and electronic components. As improved processing and manufacturing techniques drive down prices, smart chips could penetrate existing component markets while opening up substantial new applications.

Revenues for smart circuits will reach $80 million next year, according to Art Fury, VP of marketing at Siliconix (Santa Clara, Cal.), while General Electric estimates this market will zoom to $1 billion in the next ten years. That figure is conservative compared with the combined projections for individual segments being made by some market watchers.

Flat panel displays and computer printers are being targeted by many vendors, including Siliconix, Texas Instruments (Dallas), Telmos and Supertex (Sunnyvale, Cal.), Unitrode (Lexington, Mass.), and Sprague Electric (Worcester, Mass.). Harris Semiconductor (Melbourne, Fla.) and GE's Semiconductor Division (Syracuse, N.Y.) have introduced integrated circuits for motor control, while XO Industries (Mountain View, Cal.) manufactures chips for fluorescent lighting ballasts. Both GE and Motorola (Phoenix), which makes a chip for circuit protection, intend to enter the automotive market.

Smart power chips are currently used in some of the markets occupied by discrete power components, including inkjet and electrostatic printers, telephone subscriber line and ringing circuits, and switching power systems used in computers and other electronic devices. But the real potential for smart power ICs lies in opening up entirely different markets. In electronics, these new arenas include reprographic technologies, electroluminescent (EL) and gas plasma flat panel displays (primarily for portable computers), and ultrasound imaging devices.

Flat panel displays should become a major outlet for smart power, according to Richard E. Siegel, VP of sales and marketing at Supertex. He expects the proportion of portable computers using EL and gas plasma screens (instead of the liquid crystal types now widely used) to rise from about 10% at present to over 80% by the early 1990s, pushing sales of display-driver integrated circuits from $5 million to $1 billion by 1992.

"In the 1970s, microprocessors led the semiconductor industry to new markets, such as home computers and engine emission controls. Smart power chips will provide the next wave of long-term expansion by opening up electrical applications."

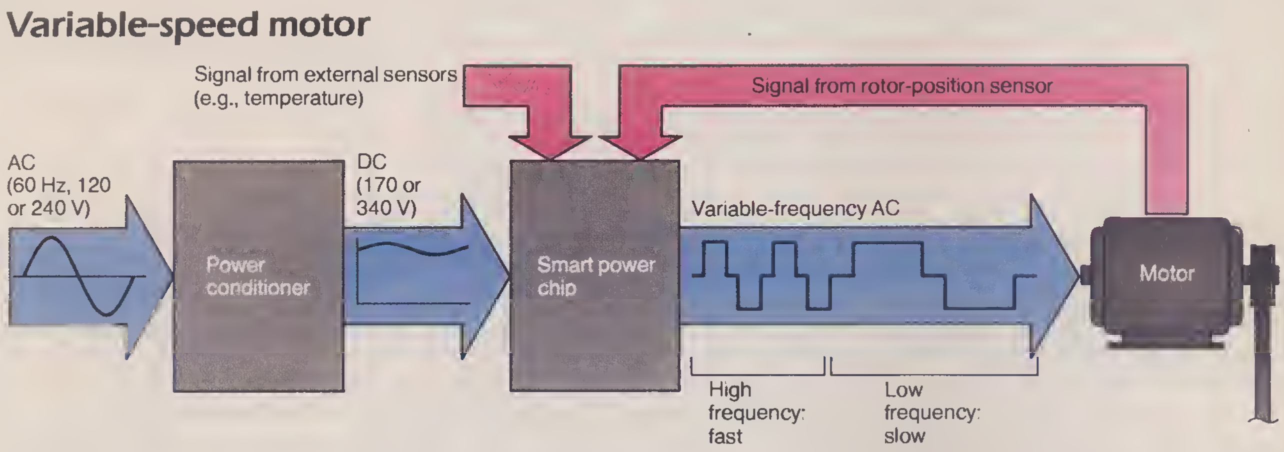
Art Fury
VP for Marketing
Siliconix

Outside of electronics, automobiles provide a potentially large market for smart power. This is because "the use of electronic devices in vehicles will go up; they provide a more accurate and trouble-free means of engine and transmission control, facilitate service diagnostics, and enable manufacturers to differentiate their cars with features not offered by competitors," says John Schnapp, VP at Temple, Barker & Sloane (Lexington, Mass.). But stuffing a car with electronics would compound the complexity of the already intricate and weighty wiring harness, unless smart ICs are used to reduce and ultimately replace this system with one multiplexed control wire. Schnapp adds that such replacement would lower labor costs since the wiring harness is the single most labor-intensive device in automobile assembly.

However, Jim Siegel, marketing manager at Ford's Electrical and Electronics Division (Dearborn, Mich.), is cautious. "We have learned that multiplex wiring is a more complicated task than once thought. It's not just a matter of removing the old wiring; many parts of the car not directly affected by wiring changes must be redesigned," he says. "In addition, auto companies are apprehensive about making changes based on an immature technology unless there are definite benefits the customer can see." Thus, Siegel expects an evolutionary development for smart power in cars, with such devices appearing first in luxury models and gradually spreading to other product lines in the mid-'90s.

Small alternating-current electric motors of less than one horsepower are another major potential arena for applying smart power. The 80 million motors produced annually that operate at fixed speeds under varying load conditions are an obvious target. Smart power ICs could considerably improve the efficiency of such motors by delivering only the amount of current required by a given task, according to Bill Groves, editor of *In-Stat Research Letter* (Scottsdale, Ariz.). The market for smart power chips to control motor speed could be enormous, since the average household contains dozens of variable-load motors in washers, dryers, refrigerators, and other appliances. Groves, however, mentions some caveats. Acceptance of smart power in the electrical industry will be slow until "the costs of the new technology are much lower than today's in-place technology, or it provides benefits that considerably surpass those of the existing technology," he says. Moreover, "smart power devices may save customers millions of dollars, but only when they save money for the motor or appliance manufacturer will they find extensive use."

Another tempting target for smart power is the 900 million fluorescent lights currently installed in the U.S. "Electrical energy costs have increased by a factor of five since 1968, but smart power lamp ballasts can reduce the energy needed to run a fluorescent light by at least 30%," says Neil Benson, chief operating officer of XO Industries. "As the reliability of such devices is demonstrated, there will be more rapid installation in office buildings, shopping malls, and other large complexes." At $25 each, these ballasts are expensive; conventional ballasts cost less than $1. But Benson estimates that energy savings could lead to a payback period of about one year. He predicts that some 2 million units will be installed next year, even if the unit price stays at the current level. ***—David Bromfield***



A motor controller containing a smart power chip could convert constant-frequency ac to dc, interpret sensor input, and decide how fast the motor should run. It could then switch the dc power on and off to achieve that speed.

tor business group (Fort Wayne, Ind.).

Smart motors could revolutionize the way appliances work. In today's air conditioners, for example, the compressor is cycled on and off repeatedly in order to maintain a desired degree of coolness. This stop/start action wears out the motor. A smart motor could run constantly, speeding up and slowing down in accordance with the continuous feedback it received from an electronic temperature monitor. Avoidance of frequent starts and stops, says Ehner, also reduces the size of the motor needed for a given horsepower output; motors are designed to be large enough to handle the surge current they draw upon starting, which is several times larger than the current drawn any other time. There are other possible uses, too. Washing machines, for example, could do without the expensive and trouble-prone mechanical transmission now used to translate a fixed-speed motor rotation into the variety of motions needed to agitate and spin the clothes.

So-called traveling appliances, such as electric hand drills and kitchen beaters, could also become more effective with an electronically commutated motor. Such machines now attain variable speed without electronic commutation by converting ac input to dc. In so doing, however, they waste a lot of power and generate radio-frequency noise that can interfere with electronic equipment in the vicinity.

Not only would an ECM increase efficiency and reduce interference, but it could make the appliances more responsive as well. An electric drill, for example, could automatically speed up to overcome the resistance of harder wood or metal, as could a kitchen beater when batter started to thicken. Such a capability would require sensing the position of the spinning rotor relative to the rotating electromagnetic field of the stationary coil. The rotor slips behind the field as the motor works against a tougher load; an electronic sensor could respond to this slippage by signaling the smart power devices to increase speed or to pass more current.

Although smart power is not a technical necessity for making an ECM, the large number of components otherwise needed may make it an economic necessity. "Until there are large quantities of smart power chips available, there won't be much electronics in motors,"

Logic signals processed on the low-voltage left side of the chip control an array of high-voltage transistors to operate a flat panel display.

says Thomas Selis, engineering manager of Westinghouse's small motor division (Lima, Ohio). GE's Ehner agrees, but adds an optimistic note. "We're now within striking distance of high-volume consumer applications" of smart variable-speed motors, he says. Ehner predicts commercial introduction of such motors with fractional-horsepower outputs during the next year. Motors of that size are commonly found in such appliances as refrigerators, air conditioners, and heat pumps.

But if U.S. appliance makers have plans for smart power products, they aren't talking about them. "They won't even tell us what they're doing," says Robert Edwards, a consultant with the National Association of Homebuilders' Smart House project (HIGH TECHNOLOGY, May 1985, p. 60); the Smart House is a proposal for integrated home control that would rely heavily on the introduction of smart appliances. Edwards says the silence stems from manufacturers' nervousness about competition from Japan, where companies such as Hitachi and Toshiba are reported to be working on similar technology.

Motor manufacturers have in general remained aloof to the attraction of smart power—largely because the products now available don't measure up to the demands of the job. "What we want is a $10 chip containing six power output devices that can handle 10 amps and 400 volts," says Maurice James, director of advanced technology at Emerson's motor division (St. Louis). "That's a long way off."

The few electronically commutated motors now available—such as the one GE makes for its variable-speed ceiling fan—still use discrete components rather than integrated smart power

chips. But "there will not be any cost breakthroughs with discretes," says GE's Ehner. "You have to integrate."

The ability to adjust a large current output with a small signal input would not be limited to motors. Another possibility involves using induction heaters to provide hot water at the tap on demand—avoiding the waste caused by storing hot water in a tank until it is called for. An induction unit produces heat in proportion to the frequency of the ac input. A temperature sensor at the faucet could send readings to the smart power chip at the heater; the chip could adjust the frequency in order to maintain the desired temperature, much as a smart motor controller adjusts frequency to vary speed. This feedback loop would be impractical without electronics that could control the induction heater's frequency according to a continuous low-voltage input signal.

Fluorescent lights are another large potential market for smart power, especially since more and more office buildings are installing computer-based energy management systems (EMS). Signals from the EMS based on time of day or on the amount of available sunlight could be fed directly to the lamp's ballast (the device that controls current flowing into the tube). A smart power chip at the ballast could act on that signal to control the light output.

Even without being connected to an EMS, a smart power lamp ballast could save energy. The key is its ability to convert the 60 Hz from the power line into a much higher frequency, typically 12 kilohertz. The high frequency makes the lamps about 10% more efficient; the light-emitting ions in the tube don't have time to revert to a non-glowing state before being zapped by another peak of current.

The advantage of higher frequency has been known for some time, and electronic ballasts are already available to peform this conversion, using many discrete components. But the introduction of smart power chips into ballasts promises a new dimension in lighting control. By cramming control and power-handling functions on the same chip, an electronic ballast could be made cheaply enough to make a dent in what has become a commodity market.

"In 10 years, all fluorescent lights will have smart power ballasts," says Peter Shackle, engineering vice-president at Telmos (Sunnyvale, Cal.). The obstacle is not so much in the technology, he says, as in the marketing. Ballast making is an old industry, and "with a chip you're breaking the rules." For example, Advance Transformer (Chicago), one of the major ballast makers, just introduced its first electronic unit—but it uses discrete components. "We are investigating smart power technology," says Alan Fisher, vice-president for marketing and strategic planning at the company, which is a subsidiary of North American Philips. And Robert Burke, engineering manager at Litton's Triad-Utrad division (Huntington, Ind.), another ballast maker, predicts it will be at least 1–3 years before smart power ballasts hit the market, and even then they will be in specialty applications.

Makers of low tech electrical equipment such as lights may hesitate before adopting something as exotic as smart power, but quicker acceptance will probably be found in the computer and peripherals industry. One or two chips, for example, might replace a board's worth of components now needed to regulate the electrical power flowing into a computer's logic circuits.

While smart power would allow some reduction in size and weight, its more important potential benefit is improved reliability. Power supplies are the single most failure-prone part of many electronic products, including personal computers; reducing the number of components should cut the failure rate. For now, a separate transformer would still be needed to step down the 110 volts from the wall into the 5-V levels used by microprocessors and other logic components.

> *"The power supply on a chip is now commercially feasible."*

Eventually, however, a small transformer might be combined with the high-voltage IC in a single package, says Thomas Daly, product manager at GE's power electronics department. Although such a hybrid configuration is now considered prohibitively expensive because it requires hand assembly, Daly predicts that cost will drop "phenomenally" with automated production techniques now being developed. Adds general manager Smart: "The power supply on a chip is now commercially feasible."

Smart power should be applied more widely outside the computer and electronics industries as the devices become able to handle larger amounts of power. The challenge is to develop chip packages that remove the heat from the silicon before damage ensues. One method is to connect the package to a large piece of metal, which serves as a heat sink. If no such heat sink is available in the system itself—as in a computer with a plastic chassis—it may be necessary to attach a metal fin to the rear of the package to conduct heat out to the air.

Most smart power devices are still made on a custom basis, but standard products are starting to appear. For example, high-voltage, low-current chips for driving flat panels are available from Texas Instruments, Siliconix, and Supertex. The latter recently licensed its technology to Mostek (Carrollton, Tex.), an established semiconductor manufacturer whose capacity for high-volume production should push prices down. Telmos expects to come out this month with a standard line of chips combining CMOS logic and 500-volt output. Motorola (Phoenix) offers devices that function exclusively as circuit protectors; the chip shuts off power if voltage or temperature exceeds a preset value. Motorola is known to be interested in supplying smart power chips for future multiplexed cars, too. The company plans to introduce a chip for this application next month. Controlled by low-voltage logic input signals, the device will switch up to 16 amps of current. So far only a few samples have been delivered, but volume production should begin around mid-year, according to product planning manager Jack Takesuye.

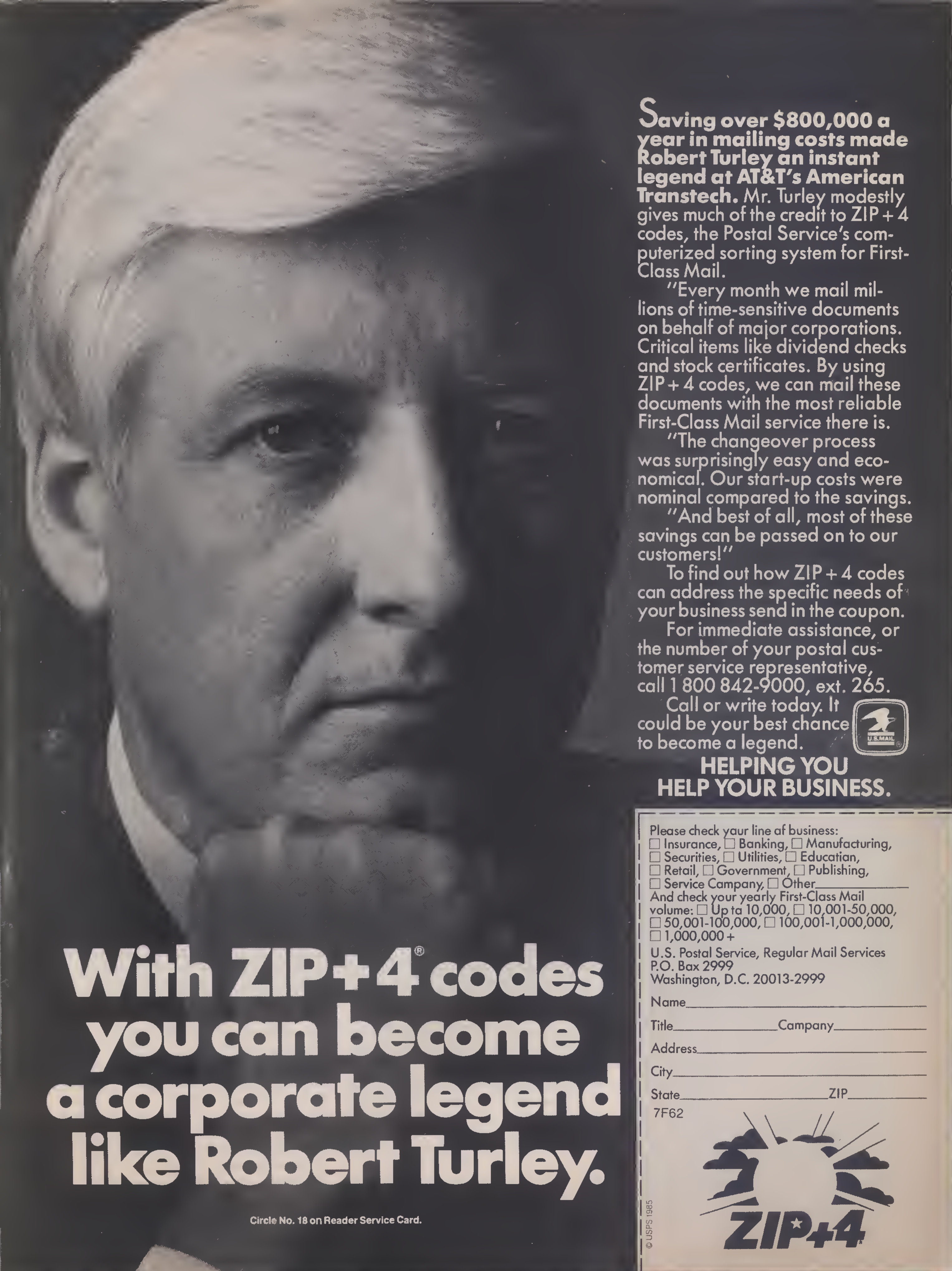
Competition should heat up with GE's recent decision to begin marketing smart power ICs. The company's semiconductor department has already been making high-voltage ICs and power MOS transistors, but until now has sold them primarily to other GE operations; the motor division, for example, uses the components in its variable-speed ceiling fan. Now the company is looking to sell smart power chips to the outside world.

GE is aiming squarely at high-volume markets. It recently built a semiconductor fabrication plant in Raleigh, N.C., and refurbished one in Syracuse specifically to make smart power devices; the two plants have a combined annual capacity of $250 million worth of chips, according to Smart.

This outpouring of smart power chips will be targeted first to makers of automobiles and electric motors. The company is betting that if smart power becomes prevalent in these ubiquitous machines, the huge volume demanded will drive prices down to where the devices will be suitable for applications now considered marginal—and for others not yet imagined. □

Herb Brody is a senior editor of HIGH TECHNOLOGY.

For further information see **RESOURCES**, *p. 69.*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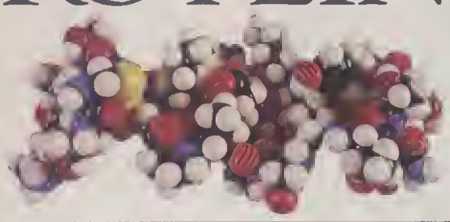


by Jonathan B. Tucker

Computer graphics and gene splicing are helping researchers create new molecules for industry and medicine

Industrial chemists have long known that for economy, efficiency, and versatility, it's hard to beat enzymes—the large proteins that catalyze reactions in living cells. Enzymes are used routinely in a wide variety of chemical processes, ranging from medical diagnostics to the production of foods, beverages, pharmaceuticals, industrial chemicals, and detergents.

Nevertheless, these workhorse molecules, consisting of hundreds of amino acids linked together in precise sequences, have not been without their limitations. One problem is that natural enzymes have evolved to function in living cells, so they are often destroyed by harsh industrial conditions such as high temperatures and pressures, mechanical stress, and organic solvents and detergents. Because most natural enzymes are too short-lived to be economical for many industrial tasks, the growth of the $600-million-a-year worldwide enzymes market has stalled in recent years.

But biotechnologists are now turning to computer graphics, DNA synthesis, and gene splicing to create versatile new enzymes. Such "protein engineering" promises to revitalize sales by yielding tougher, more efficient enzymes that are tailored to specific industrial processes.

Artificial enzymes could result in new drugs, agricultural chemicals, and functional components for bioelectronic devices, as well as catalysts for reactions not performed by living organisms. Another result could be entirely new classes of polymers that are much richer, structurally and functionally, than the materials now possible with conventional organic chemistry. Novel structural proteins, for example, could be modeled after wool, silk, or even spider webs to yield more natural-looking or less flammable synthetic fabrics and superstrong, lightweight materials.

Several U.S. companies have been sold on the idea, and are investing heavily in protein-engineering research. Some of the more prominent players in the field include Monsanto (St. Louis), Upjohn (Kalamazoo, Mich.), and DuPont (Wilmington, Del.). Since 1982, Exxon's research laboratory in Clinton, N.J., has had a joint research agreement with Cold Spring Harbor Laboratory (Cold Spring Harbor, N.Y.) for modifying nitrogen-fixing enzymes (proteins that preclude the need for synthetic fertilizers by extracting nitrogen from the atmosphere in a form usable by plants). Across the Atlantic, Plant Genetic Systems (Ghent, Belgium) has organized a protein-engineering consortium of scientists from several European countries, and six chemical and pharmaceutical companies in the U.K. have formed a Protein Engineering Club to finance research at British universities.

Form equals function. Natural proteins come in a wide assortment of shapes and sizes. But they all consist of linear chains in which each link is an amino acid molecule. An enzyme is typically made up of 300 to 500 amino acids (of which there are 20 different types) in a specific sequence. This entire sequence is coded for by a gene (a sequence of nucleotides—chemical "building blocks"—within a DNA molecule). And each amino acid in the sequence is specified by a three-nucleotide segment along the DNA molecule, called a codon. If one codon is replaced by another, or if one nucleotide within the codon is changed, the result may be a different amino acid and hence a modified protein.

The active form of a protein is not a linear chain of amino acids, however, but an intricately folded version of the chain. No two proteins fold up in exactly the same way, just as a length of string crumpled up in one hand differs from one crumpled up in the other. In the case of proteins, the 3-D configuration of the folded chain depends on the sequence of amino acids, whose chemical side chains extend out from the molecule's "backbone." The 20 different amino acids each have distinctive side chains that differ greatly in their shape, size, electric charge, and chemical properties. During protein folding, adjacent amino acid side chains with the same charge repel one another and move apart, while amino acids with oppositely charged side chains move together and form bonds that stabilize the folding pattern. Similarly, water-repelling amino acids tend to cluster in the center of the folded protein where they are shielded from solvent molecules. The result of this folding process is a convoluted, densely packed structure that determines the protein's function.

In enzymes, the folded chains form a groove or pocket on the surface of the

RON KINMOTH

Molecular biologist Kevin M. Ulmer, seen here in Genex Corp.'s molecular graphics facility in Gaithersburg, Md., claims that protein engineering is now at the same point that gene splicing was in the mid-1970's. By wedding computers to biotechnology, Ulmer and other researchers are creating versatile new enzymes, hormones, and anticancer drugs.

protein, known as the active site, where catalysis—the accelerating of chemical reactions—takes place. This pocket is shaped so that the substrate (the molecule on which the enzyme acts) fits into it snugly, much as a key fits into a lock. Inside the active site, amino acids that are far apart in linear sequence—say, at positions 51 and 239—may find themselves close together because of the folded configuration. Changing just one of these adjacent amino acids often has the effect of altering the architecture of the active site. That, in turn, can dramatically modify the enzyme's catalytic efficiency or specificity for a particular substrate.

An enzyme not only holds the substrate in the proper orientation but may actually take part in the reaction by donating electrons or protons. The result is that reactions are speeded up millions of times at normal temperatures and pressures. And because enzymes are much more specific than inorganic catalysts such as metals and zeolites, they provide higher yields

and fewer wasteful and polluting byproducts.

Major commercial enzymes include rennin, which coagulates milk in cheesemaking; alpha-amylase, amyloglucosidase, and glucose isomerase, which together convert corn starch into high-fructose corn syrup; proteases (protein-attacking enzymes), which are used in industrial processes and added to laundry detergents to remove protein stains; and urokinase, which dissolves blood clots in the body.

New sequences. Scientists have recently learned how to remodel proteins by replacing one amino acid with another at predetermined positions along the protein chain. These new methods are much more precise than older techniques, such as exposing bacteria to chemicals, ultraviolet light, or radiation. With those methods, scientists could not control where the mutations arose, nor could they easily substitute amino acids at sites of particular interest, such as the active site of an enzyme.

One of the new techniques is called site-directed mutagenesis—essentially a means of rewriting the genetic sequence so that a gene makes a different protein. By replacing a short segment of the natural gene with synthetic DNA, researchers modify a codon for one amino acid so that it specifies a different amino acid. The altered DNA is then cloned—inserted into bacterial cells, which copy it many millions of times. Finally, the cloned gene is expressed; that is, it directs the bacteria to produce a large quantity of protein molecules containing the new amino acid.

Site-directed mutagenesis was used last year in England to remodel the active site architecture of the enzyme tyrosyl-tRNA-synthetase, which is involved in protein synthesis. Alan Fersht and David Blow of Imperial College (London) and Greg Winter of the Medical Research Council Laboratory of Molecular Biology (Cambridge) modified the enzyme's amino acid sequence by replacing the amino acid threonine with proline at a single position in the chain. The surprising result was that even this simple change of one amino acid increased the enzyme's catalytic activity 25-fold.

But site-directed mutagenesis can change only one amino acid at a time; it is therefore impractical for testing the full range of 20 amino acids at a given position in the chain. A modified technique, called cassette mutagenesis, was developed by Genentech (South San Francisco) to permit such systematic studies. The scientists synthesize a complete set of DNA fragments (called cassettes) that contain codons for each of the 19 possible amino acids that remain. The cassettes are then plugged into the parent DNA molecule in place of the existing codon. Cloning and expressing genes that contain each of the cassettes yields 19 variant proteins, which differ from the native protein and one another by a single amino acid.

Chemistry by computer. Interactive computer graphics is also becoming an important tool for designing new proteins by predicting how specific changes in the amino acid sequence will alter a protein's three-dimensional structure, and hence its function. Computer modeling, which has largely replaced expensive and unwieldy physical models of large proteins, allows designers to "build" molecules on a computer screen, thereby avoiding costly trial and error in the laboratory.

First, the protein must be highly purified and crystallized—a task that can take a year or more. The crystals are then subjected to x-ray crystallography, in which x-rays are passed through a crystal from several angles. The resulting images are fed into a computer, which calculates and maps the electron density in the protein crystal. The crystallographer then fits the known amino acid sequence of the protein to the electron density map to obtain a detailed 3-D molecular model showing the positions of all the atoms in the intricately folded chain.

The chief drawback of this technique is that solving the crystal structure of even a medium-sized protein takes about five years. As a result, detailed structures of only about 100 proteins are known. Technological improvements such as electronic x-ray detectors and special-purpose hardware and software are speeding up the process, but x-ray crystallography still requires a major investment of time, labor, and money.

Once the crystalline structure of a protein has been determined, however, the spatial coordinates of its atoms can be displayed graphically at an interactive computer-graphics workstation, such as the Evans & Sutherland Picture System 300. The designer can then test out an amino acid substitution on the screen; working within the predetermined constraints of bond lengths, angles, and energies, the interactions between the new amino acid and its neighbors can be assessed. For example, the substitution of a particular amino acid at a critical site may strain the backbone of the enzyme, alter the configuration of its active site, or improve or impair its catalytic activity.

One way to make proteins more stable at high temperatures is to link adjacent loops of the chain with disulfide (–S–S–) bridges between two nearby sulfur-containing amino acids. The bridge reduces the tendency of the chain to unfold at high temperatures and thus enhances its thermal stability. Molecular graphics has been used to select sites in a protein where the geometry is suitable for inserting such bridges without disturbing the rest of the molecule.

Computer simulation is another way of predicting the perturbations in the known 3-D structure of a protein that would result from specific changes in its amino acid sequence. For example, a molecular-mechanics program can calculate the forces between all the atoms in a protein for a large number of different molecular conformations. The computer then selects the lowest-energy (and thus most stable) folding pattern.

Because the number of possible conformations is very large, solving the minimum-energy structure for even a small protein requires a great deal of computing power; a powerful supermini such as Digital's VAX-11/780 provides only a rough approximation of the structure of a modified protein. Nevertheless, "even an imperfect model gives the biochemist and the molecular geneticist a handle on the problem," says Richard J. Feldmann, a molecular-graphics specialist at the National Institutes of Health (NIH) in Bethesda, Md. Predictions from modeling studies can also be tested by experiment, providing a continual interplay between theory and practice.

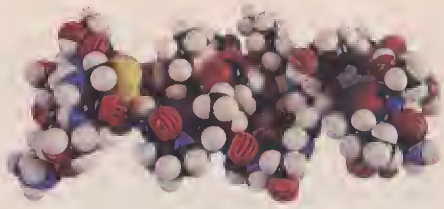
Engineering enzymes. Several biotechnology firms have already begun to engineer proteins, albeit at different levels of sophistication. Cetus (Emeryville, Cal.) has modified two proteins used in experimental cancer treatment (beta-interferon and interleukin-2) to improve their stability. With the beta-interferon, for example, site-directed mutagenesis was used to change one amino acid in the protein chain (cysteine to serine), so that the protein would fold properly when manufactured by bacteria. The two engineered proteins are now in clinical trials.

Genex (Gaithersburg, Md.) has a special protein-engineering group that was started in 1983 with a five-year, $16.5 million contract from Bendix (Southfield, Mich.). Commercial products under development include improved alkaline proteases (the enzymes used in laundry detergents), human growth hormone (to be used as a therapeutic drug), and a protein to be used in biosensors, according to Genex senior vice-president David A. Jackson.

Repligen (Cambridge, Mass.) is using site-directed mutagenesis to modify lig-

ninase, a fungus-derived enzyme used in the pulp and paper industry to digest lignin, one of the structural components of wood. (The company specializes in industrial enzymes for pulp and paper, biofouling control, personal care, agricultural chemicals, and food processing.) Company researchers first employed conventional ultraviolet mutagenesis and selection to obtain a mutant fungus with enhanced ligninase activity. Then they cloned the gene for the enzyme and determined its DNA base sequence. They are currently using site-specific mutagenesis to further enhance the enzyme's activity and stability. Repligen plans to market its engineered ligninase in about four years, according to E. Michael Egan, manager of business development.

Foodmaking enzymes are also being remodeled through protein engineering. At Miles Laboratories (Elkhart, Ind.)—the leading U.S. manufacturer of industrial enzymes—researchers are working with chymosin, an enzyme used to coagulate milk in cheesemaking. After chymosin has done its job, the curds are heated to inactivate the enzyme, but some low-level activity persists. When sharp cheddar cheese is



aged (for up to six months), chymosin continues to break down milk proteins and can produce a bitter flavor. Miles is using site-directed mutagenesis to engineer a modified form of the enzyme that will be fully inactivated by heating, according to Gary A. Wilson, director of microbiological research in the company's Biotechnology Group.

Researchers at Genentech and Genencor (South San Francisco) have been exploring the effect of single amino acid substitutions in the structure of subtilisin, a protein-digesting enzyme used in detergents. Since the 3-D crystal structure of subtilisin was known, molecular graphics was used to identify key amino acid units involved in substrate binding and catalysis and to model the effects of various amino acid substitutions. The studies suggested that inserting a different amino acid at position 166 (glycine in the native protein) would alter the enzyme's active site, possibly improving its efficiency. The second target for substitution was the methionine at position 222; this amino acid is easily oxidized, resulting in a 90% activity loss when the enzyme is exposed to bleach.

Using cassette mutagenesis, the team made several new forms of subtilisin by trying out each of the remaining 19 amino acids at the two chosen positions. Although the new enzymes differed from one another by only a single amino acid, they were substantially different from the original molecule in catalytic activity, substrate specificity, and thermal and chemical stability. Amino acid substitutions at position 166 yielded several enzymes with reduced catalytic activity and one with higher overall activity. Substitutions at position 222 yielded several variants that were more resistant to oxidation yet just as active; one variant even showed increased activity.

Models of the alpha helix, a regular folding pattern that occurs in many proteins, are examined by DuPont scientists William F. DeGrado and Patricia C. Weber. DuPont is synthesizing an artificial protein consisting of four interconnected alpha helices.

Richard J. Feldmann directs a state-of-the-art molecular graphics facility at the National Institutes of Health. On screen is a 3-D model of a sodium channel, a complex of proteins that controls the passage of sodium ions across the cell membrane.

TERESA ZABALA

Synthesis from scratch. The greatest challenge facing protein engineers is to create enzymes and other proteins in the laboratory that do not exist in nature. "Our ultimate goal," says William F. DeGrado, a mo-

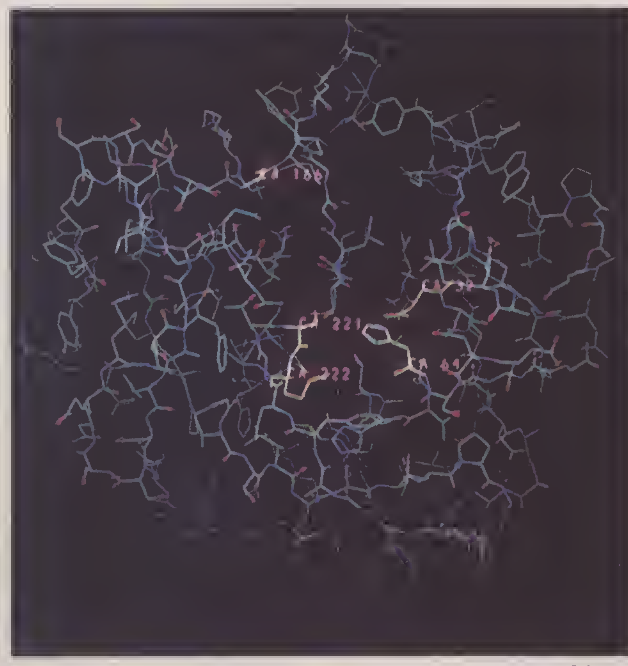
lecular biologist and principal investigator at DuPont's Central R&D facility (Wilmington, Del.), "is to design enzymes that will catalyze reactions that aren't catalyzed by natural enzymes." To this end, research groups are using automated "gene machines" and conventional chemistry to synthesize entire new genes. Gene machines can be programmed to produce enough DNA, in just a day's time, to code for a chain of 40 amino acids (HIGH TECHNOLOGY, March 1984, p. 50). This approach has already resulted in a more biologically active version of the antiviral protein alpha-interferon, and may eventually yield a wide array of new artificial proteins.

Scientists at Amgen (Thousand Oaks, Cal.) used DNA synthesis to create the engineered version of alpha-interferon. First they compared the amino acid sequences of several natural alpha-interferons from different species. Then, for each position in the redesigned protein, they selected the amino acid that appeared the most times in the natural interferons. After that, this "consensus" amino acid sequence was translated into the corresponding DNA sequence. Finally, the DNA molecule was synthesized in sections, pieced together, and cloned and expressed in bacteria to yield the engineered protein.

Amgen's redesigned alpha-interferon has more activity per unit weight than any of the natural proteins on which it was based, according to Gordon M. Binder, Amgen's vice-president for finance. The engineered sequence also has an unexpected effect: In tests on hamsters, it protects against a human cancer, while natural alpha-interferon does not. Upcoming clinical trials will determine whether the protein has a similar inhibitory effect in humans.

Another approach is to make proteins in the test tube through conventional organic chemistry, coupling amino acids together one at a time. One method, called solid-phase protein synthesis, involves growing chains of amino acids on microscopic polystyrene beads. The amino acid units can be linked together in any predetermined sequence through a series of reactions. This method won the 1984 Nobel Prize in chemistry for Bruce Merrifield of Rockefeller University (New York), and is now used routinely to make small proteins of 50–100 amino acids.

The chief advantage of chemical synthesis over gene-cloning technology is that it provides more freedom for experimentation. While bacteria can make proteins containing only the 20 amino acids specified by the genes, the organic chemist has approximately 2000 natural and man-made amino acids from which to choose. And while biological systems have evolved to use only one molecular form, or isomer, of amino acid—the "left-handed" structure called L, for *levo*—chemists can synthesize the mirror-image right-handed (D, for *dextro*) forms and incorporate them into artificial proteins; the resulting molecules may have useful properties not found in the L forms.



Researchers at Genentech and Genencor used protein engineering to alter the amino acid sequence of the enzyme subtilisin at positions 166 and 222 along the chain, as indicated in this computer-generated model. These amino acid substitutions induced slight changes in the structure of the protein, some of which significantly improved its activity and stability.

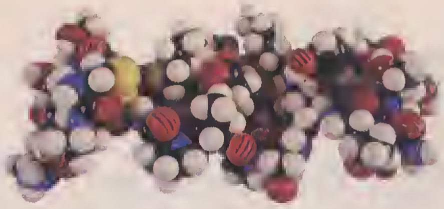
But even though chemical synthesis of artificial proteins offers greater flexibility, genetic engineering methods provide important advantages for large-scale production. For proteins larger than 20–30 amino acids, chemical synthesis tends to be costly, has low yields, and generates a complex mixture of side-reaction products, making the desired protein very difficult to purify. Thus for large artificial proteins such as enzymes, it may be preferable to synthesize a long piece of synthetic DNA corresponding to the protein and then clone and express the synthetic gene in bacteria. Using a bacterial fermenter, large quantities of product can be generated. "It's inconceivable that chemical methods will ever be able to synthesize large proteins as cheaply and easily as living systems," argues Genex's Jackson.

The best approach may be a combination of the two techniques, says David Richardson, associate professor of biochemistry at Duke University School of Medicine (Durham, N.C.). Protein designers would first employ chemical synthesis to knock out a rough version of the artificial protein molecule, he says, and then use the information gained at that stage to prepare a genetic design.

Revised hormones. Several relatively simple peptide hormones (containing fewer than 100 amino acids) have been designed and chemically synthesized using the solid-phase method. Unlike the complex folding pattern of enzymes, in which amino acids far apart in linear sequence come into close spatial proximity, peptide hormones consist of discrete sections. The strong physiological effects of hormones also makes it easy to assess the impact of structural changes on the molecule's biological function.

A Rockefeller University team has designed analogs (modified versions) of peptide hormones such as the brain chemical beta-endorphin, eliminating parts of the molecule that are not essential to its biological activity. The team, led by biochemistry professor Emil T. Kaiser, has also redesigned the hormone calcitonin, which regulates blood calcium levels and has FDA approval for the treatment of bone-wasting syndromes such as Paget's disease and osteoporosis. In these cases, molecular modeling was used to analyze the 3-D structure of calcitonin to determine how each part of the molecule functions. The researchers then designed and synthesized an analog of the hormone that differs from the natural protein in 60% of its 32 amino acids yet has the same overall folding pattern and biological activity.

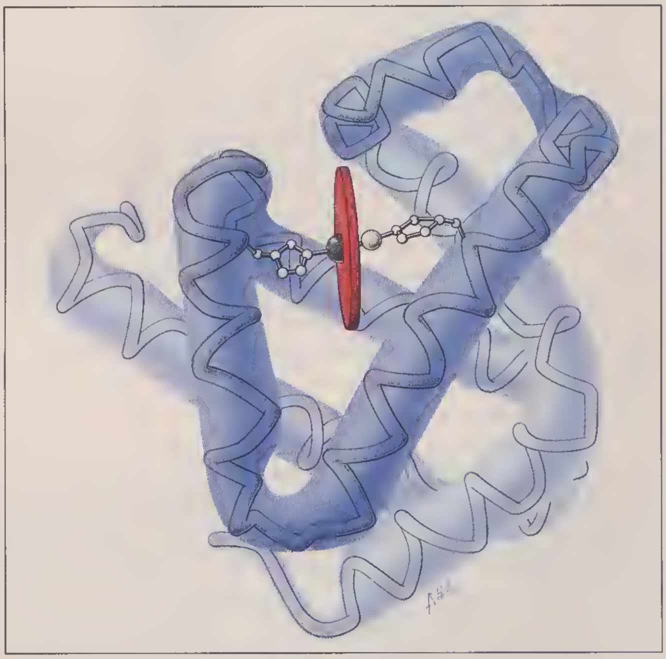
For example, amino acid positions 8–22 correspond to the part of calcitonin that binds to a complementary receptor site on the cell surface. This sequence folds up into a secondary structure called an amphiphilic helix, with water-repelling amino acids on the side that interacts with the receptor and water-attracting amino acids on the side exposed to the solvent. The researchers found that as long as they used a sequence of amino acids that formed an amphiphilic helix, the exact units didn't matter.



Kaiser's group has recently produced some calcitonin analogs with greater biological activity than the natural hormone. And while natural calcitonin can be broken down by enzymes in the stomach and hence must be injected, artificial calcitonin may be resistant to such attack. Because of these advantages, Kaiser is patenting his calcitonin analogs and negotiating with some pharmaceutical companies.

How will it fold? Although it is still impossible to predict the precise 3-D structure of a large protein from its amino acid sequence alone, protein chemists are beginning to learn how to design sequences of amino acids that will fold up into regular, repeating structures. Two such folding patterns occur in natural proteins. In the alpha, or helical, pattern, the main chain forms a tight coil stabilized by internal hydrogen bonds, with the amino acid side chains extended outward in a helical array. The beta, or pleated-sheet, pattern consists of parallel strands of protein chain running in opposite directions, stabilized by hydrogen-bonding interactions between the strands.

These two folding patterns are the foundation for a number of artificial proteins that have been designed from basic structural principles. In 1983, Berndt Gutte of the Biophysical Institute of the University of Zurich designed and chemically synthesized a simple protein that binds the pesticide DDT. This protein is a chain of 24 amino acids that folds up into a four-stranded beta sheet with six amino acids in each strand, forming a relatively flat structure. Gutte designed the active site by building a model of the protein and packing the amino acid side chains around a model of the DDT molecule. The side chains of the beta sheet form a T-shaped cleft into which the DDT molecule binds with weak affinity (but significantly better than by mere chance).



MARK E. ALSOP

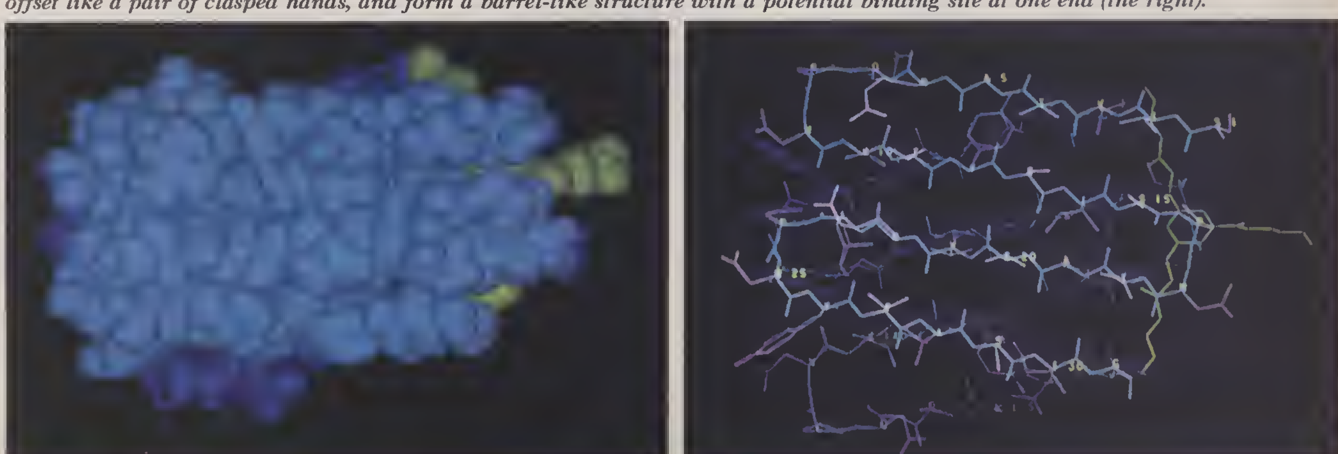
Intricate structure of the protein myoglobin shows how the chain of amino acids folds up into a compact, biologically active form. Located in muscle, myoglobin serves as a reserve supply of oxygen. The disk-shaped molecule inside the protein is a heme group, which binds oxygen.

A prototypical binding protein based on the alpha helix has been synthesized at DuPont. The design, created by DeGrado and his co-workers and based on a wide range of natural helical proteins, is a bundle of four connected alpha helices that, because of slight perturbations caused by the sidechains, are not truly parallel but are inclined by 20° with respect to one another. The team has chemically synthesized the four-helix bundle and crystallized the pure protein; spectral data suggest that the amino acid chain has folded up in the predicted manner, but final proof rests with the crystal structure, which David Eisenberg, an x-ray crytallographer at UCLA, is now trying to solve.

Because the four helices in the bundle are offset, they flare out at either end, creating a potential binding site. Once the DuPont team is certain that the helical framework folds up correctly and predictably, they plan to extend the ends of the helices to form a pocket that will bind small molecules.

A four-helix bundle is also being designed by Duke's David Richardson and his wife, Jane Richardson (likewise an associate biochemistry professor at the university). Their work differs from DeGrado's in that they plan to produce the protein by gene cloning in bacteria rather than by chemical synthesis. The protein, dubbed Felix, was designed at a Duke graduate seminar in early 1985. "The class met once a week to discuss the literature on naturally occurring helical proteins, including the contacts and connections between

Betabellin, an artificial protein designed at Duke and Rockefeller Universities, is shown in two complementary representations. The image at left shows the 3-D surface of the molecule; the image at right reveals its carbon skeleton. The molecule consists of a pair of identical protein sheets (light blue and dark blue) held together at one end by a cross-linking molecule (yellow). The two sheets are offset like a pair of clasped hands, and form a barrel-like structure with a potential binding site at one end (the right).



RICHARD FELDMAN

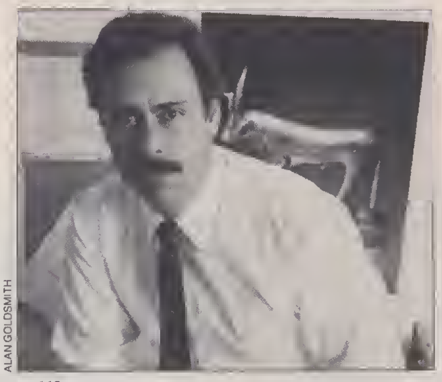
BUSINESS OUTLOOK

New proteins: bigger enzyme markets

Industrial enzymes—substances used to catalyze biochemical reactions—constitute the largest current market for proteins used in commercial process applications. Sales of such enzymes in the U.S. were $200 million in 1984, half the worldwide level, and should reach $255 million by 1988, according to Frost and Sullivan (New York). This relatively slow annual growth rate of 6.5% could pick up in the future as a result of improvements in enzyme structure and performance brought about by protein engineering.

Approximately half the sales of industrial enzymes in the domestic market are for three substances: two amylases that digest starch to produce simple sugar, and glucose isomerase, which converts this sugar into alcohol and high-fructose corn syrup. Capturing another 20% of the market are enzymes used in the dairy industry—mainly rennin for cheesemaking—and enzymes used as stain removers in detergents. Half the U.S. enzyme sales are shared almost equally by Novo Laboratories (Wilton, Conn.), the American subsidiary of Denmark's Novo Industri; and G.B. Fermentation Industries (Des Plaines, Ill.), an affiliate of Gist-Brocades of the Netherlands. Miles Laboratories (Elkhart, Ind.) is the third leading supplier, and other significant players are Rohm and Haas (Philadelphia), Pfizer (New York), Genex (Rockville, Md.), and Genencor (South San Francisco), a joint venture of Genentech and Corning Glass.

The market has been limited to date because most enzymes would be inactivated by such factors as the high temperature, pressure, and acidity present in many industrial environments. Moreover, enzymes can't work on the petrochemicals used as raw materials in most industrial processes, and the capital costs of converting to more enzyme-compatible stock would be high. As a result, "there have been relatively few new industrial uses of enzymes in recent years," says Gary Wilson, director of microbiological research at Miles. In addition, traditional markets are pretty much saturated.



ALAN GOLDSMITH

"It's not sufficient for enzymes to do unique and wonderful things. They will just sit on the shelf unless process engineers are aware of their relevance and utility."

Don Krull
Manager of Sales, Service, and Development
Novo Laboratories

But present products do offer some room for expansion. For instance, enzymes were dropped by detergent formulators in the 1970s because of fears that workers might develop allergies caused by enzyme dusts. As a result, only 15% of U.S. detergents presently contain an enzyme additive. But this proportion is now increasing, thanks to a process that eliminates dust by forming the enzyme into beads coated with wax.

On the horizon are possibilities for more dramatic growth in enzyme use. "With protein engineering, the properties of an enzyme can be changed to enhance its catalytic efficiency and ability to work in environments to which it is not naturally attuned," says Shelley Roth, director of corporate communications at Genex. Such tailored enzymes could stimulate sales in present markets and open up new niches not currently amenable to enzyme use. For example, the market for subtilisin and other enzyme stain-removers would be improved with the commercialization of an enzyme with greater resistance to oxidation and other sources of inactivation, according to Jonathan MacQuitty, director of commercial development at Genencor. If the catalytic capability of the glucose isomerase enzyme could be enhanced, less of this substance would be needed to convert a given amount of glucose to fructose. And an increase in the glucose enzyme's ability to cope with acidity would lower the need for acid-reducing chemicals in fructose manufacturing, thus reducing the cost of the whole process.

Pollution control could also offer a potential new market for enzymes. In the pulp and paper industry, for example, the waste water that results from the use of chlorine in the pulping process creates a serious disposal problem. But E. Michael Egan, manager of business development at Repligen (Cambridge, Mass.) says that such pollution would be substantially reduced if the chlorine were replaced by a ligninase enzyme altered from one that is naturally occurring.

JOHN TROHA

"As with genetic engineering ten years ago, nobody has yet generated a commercial product using protein engineering. But redesigned enzymes hold the promise of opening new, large-scale industrial applications."

Kevin Ulmer, Director
Center for Advanced Research in Biotechnology
University of Maryland

It will not be cheap to devise such enzymes. "A full research effort could last five years, with an operating cost of at least $15 million—not counting the scale-up cost to actually manufacture the enzyme," says Kevin M. Ulmer, director of the Center for Advanced Research in Biotechnology (Rockville, Md.). But Repligen's Egan believes the effort is worthwhile. "Enzymes can be more effective than chemical catalysts and obviate problems of waste and hazardous working conditions. Thus, suitably modified enzymes could take over as catalysts wherever chemicals are used in industrial processes." ***—Jeffrey Fox***

helices," says David Richardson. "We tried to work up an amino acid sequence that would yield a pair of connected helices, and then a four-helix cluster." Molecular graphics and energy-minimization techniques helped to predict what the protein's 3-D structure would look like.

The amino acid sequence of Felix was recently sent to Richard Ogden, a molecular biologist at the Agouron Institute (La Jolla, Cal.), who is now working out a DNA coding sequence for the protein. The synthetic gene is being designed to incorporate a number of unique restriction sites (sequences that signal a specific enzyme to cut the DNA molecule at that site), so that the adjacent DNA sequences can be removed or inserted at will. The restriction sites (which do not adversely affect the desired amino acid sequence) will therefore make it possible to refine the protein design by altering specific portions of the gene. When the DNA sequence is complete, Ogden plans to synthesize it chemically, clone and express the gene in bacteria, and solve the crystal structure of the resulting protein. "Comparing the actual structure of Felix with the predicted structure will tell us how

good our techniques are," says David Richardson.

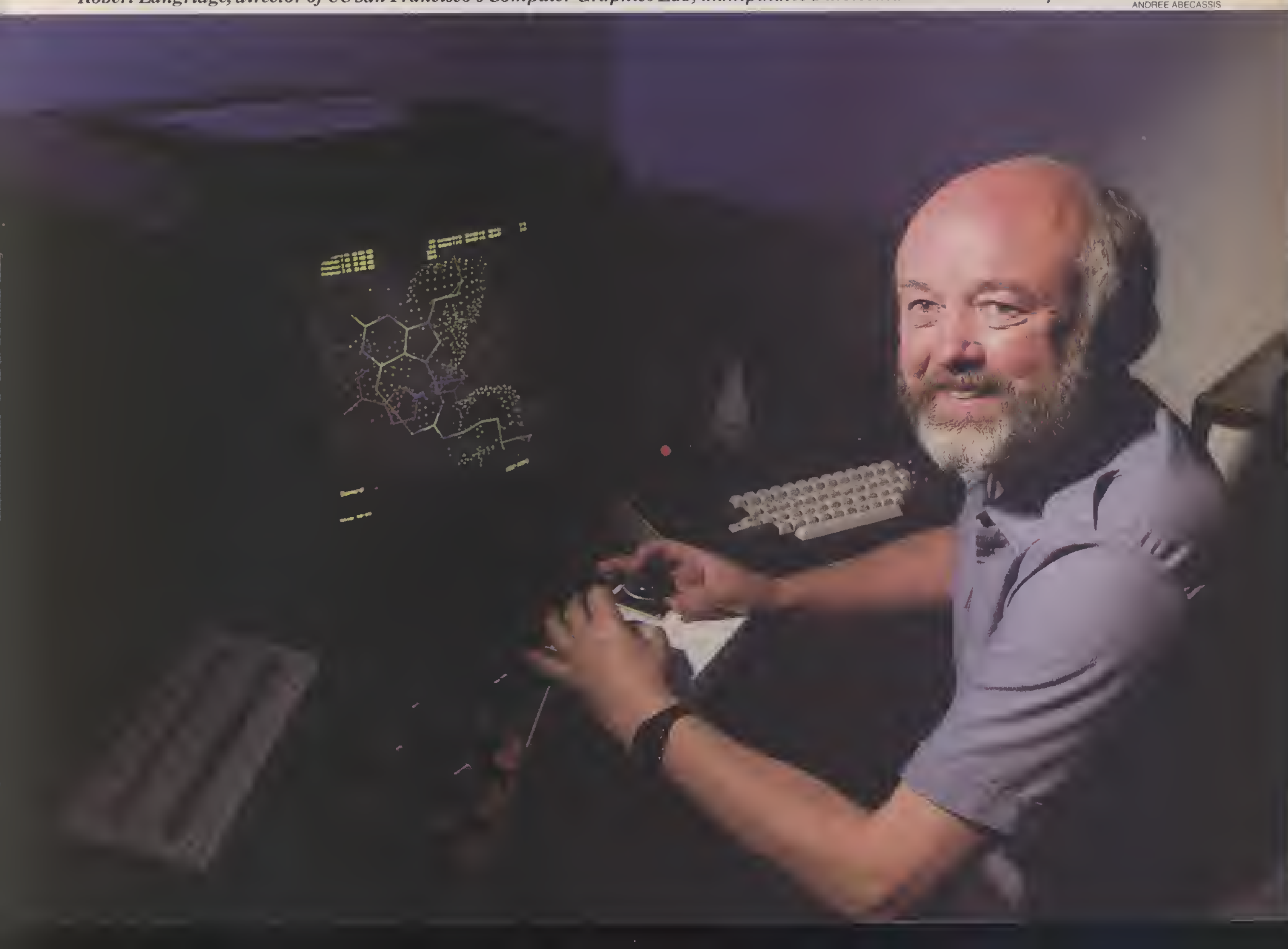
At Rockefeller University, biochemistry professor Bruce W. Erickson is collaborating with the Richardsons on the design and synthesis of another totally synthetic protein called betabellin, an abbreviation of "beta barrel bell-shaped protein." Betabellin consists of two identical chains of 31 amino acids, which fold up into a pair of beta pleated sheets with water-repelling amino acids on one side and water-attracting amino acids on the other. The two sheets are held together at one end by a cross-linking molecule to form a barrel-like structure. "The beta barrel is a design theme found in natural proteins," says Erickson. "But we have employed a different sequence of amino acids to create a structure that is far more regular and symmetrical than any of the beta barrels observed in nature."

To date, Erickson and his co-workers have synthesized several variants of betabellin. In betabellin 2, the two beta sheets are held together only at one end and thus tend to flop open. In betabellin 3, a disulfide bridge holds the two beta sheets together, stabilizing the molecule. As far as can be determined by indirect means, the betabellins have folded up according to the predicted structures. The proteins were recently crystallized, and final proof will come when the Richardsons solve their 3-D structures by x-ray crystallography.

Meanwhile, Erickson is already designing the next generation of betabellins, designated 4 and 5, which will incorporate a number of novel features. For example, in the tight hairpin turns between the strands of the beta sheet, two left-handed (L) amino acids will be replaced by their right-handed (D) isomers, which do not occur in nature. The use of the D isomers should theoretically minimize crowding between the amino acids at this position, providing a more stable structure.

Using betabellin as a scaffolding, Erickson plans to build an active site by inserting amino acids with binding or catalytic functionality into the loops at

Robert Langridge, director of UC San Francisco's Computer Graphics Lab, manipulates a molecular model on a computer screen. ANDREE ABECASSIS

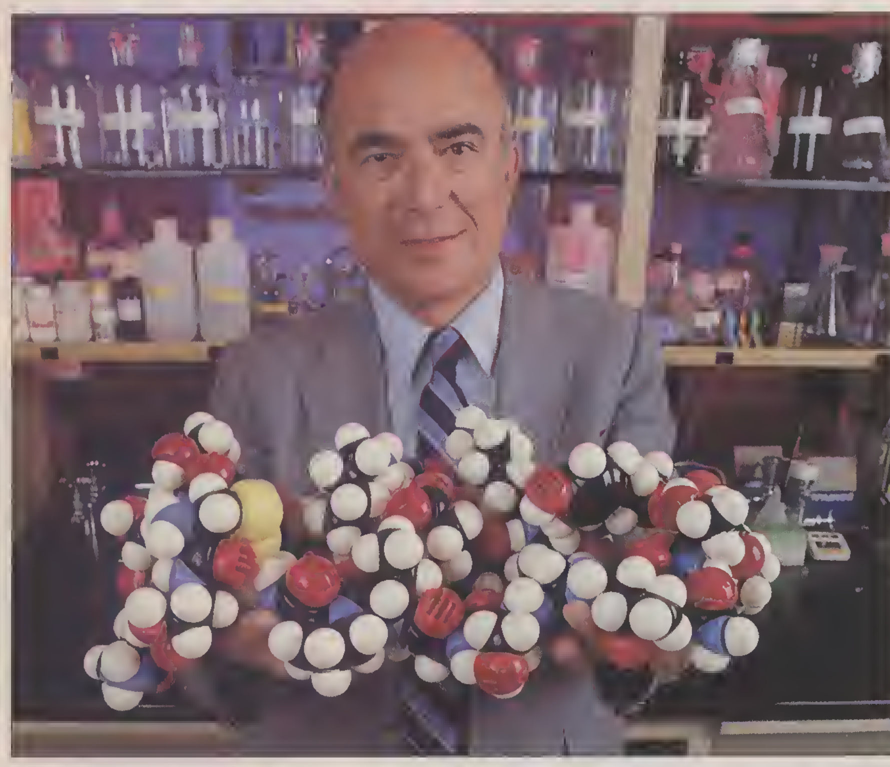


the front end of the molecule, where the two beta sheets come together like a pair of jaws. "We want to keep most of the protein constant and go in and change just one end of the molecule by adding, deleting, and substituting amino acids," he says. Erickson contends that it should be possible to construct a binding site in the next few years, but he adds that it will probably be 5-10 years before this emerging technology finds commercial applications.

Predicting by computer. New computer algorithms are being developed to help researchers simulate the complex phenomena that determine protein structure. The long-term objective is to predict which of the millions of possible amino acid substitutions in a large protein will yield a desired property, such as increased thermal stability or catalytic activity.

A first step toward this goal is to start out with the 3-D structure of a natural protein obtained by x-ray crystallography and predict how specific amino acid substitutions will cause the chain to refold. Since this type of analysis involves testing a large number of possible conformations to find the one that is thermodynamically most stable, it demands a large amount of computing power—much more than is generally available. Over the next few years, however, the situation should improve dramatically as special-purpose computers come on line. NIH's Feldmann is building a programmable array processor for molecular-mechanics calculations, a machine that will operate about 500 times as fast as a VAX-11/780 supermini.

Another molecular-mechanics processor, called Fast Run, is about a year away from completion, according to Cyrus Levinthal, a professor of biology at Columbia University. Levinthal is collaborating on the project with the Brookhaven National Laboratory. The processor "calculates the force on each atom due to pairwise interaction, the most time-consuming part of the overall computation," he explains; the rest of the calculations can then be done on an array processor.



RAY ELLIS

Emil T. Kaiser, professor of biochemistry at Rockefeller University, holds a model of synthetic calcitonin, an engineered form of a natural peptide hormone that regulates blood calcium levels. (A peptide is a small version of a protein.) The engineered hormone appears to be superior to the natural hormone in both its potency and its persistence.

When Feldmann's array processor is combined with Fast Run, it will have a speed of 750 megaflops (million floating-point operations per second)—the equivalent of 10 Cray-1 supercomputers or about 3000 VAXes, at about 2% of the cost. That huge amount of computing power should allow researchers to perform energy-minimization and dynamics calculations for fairly large proteins.

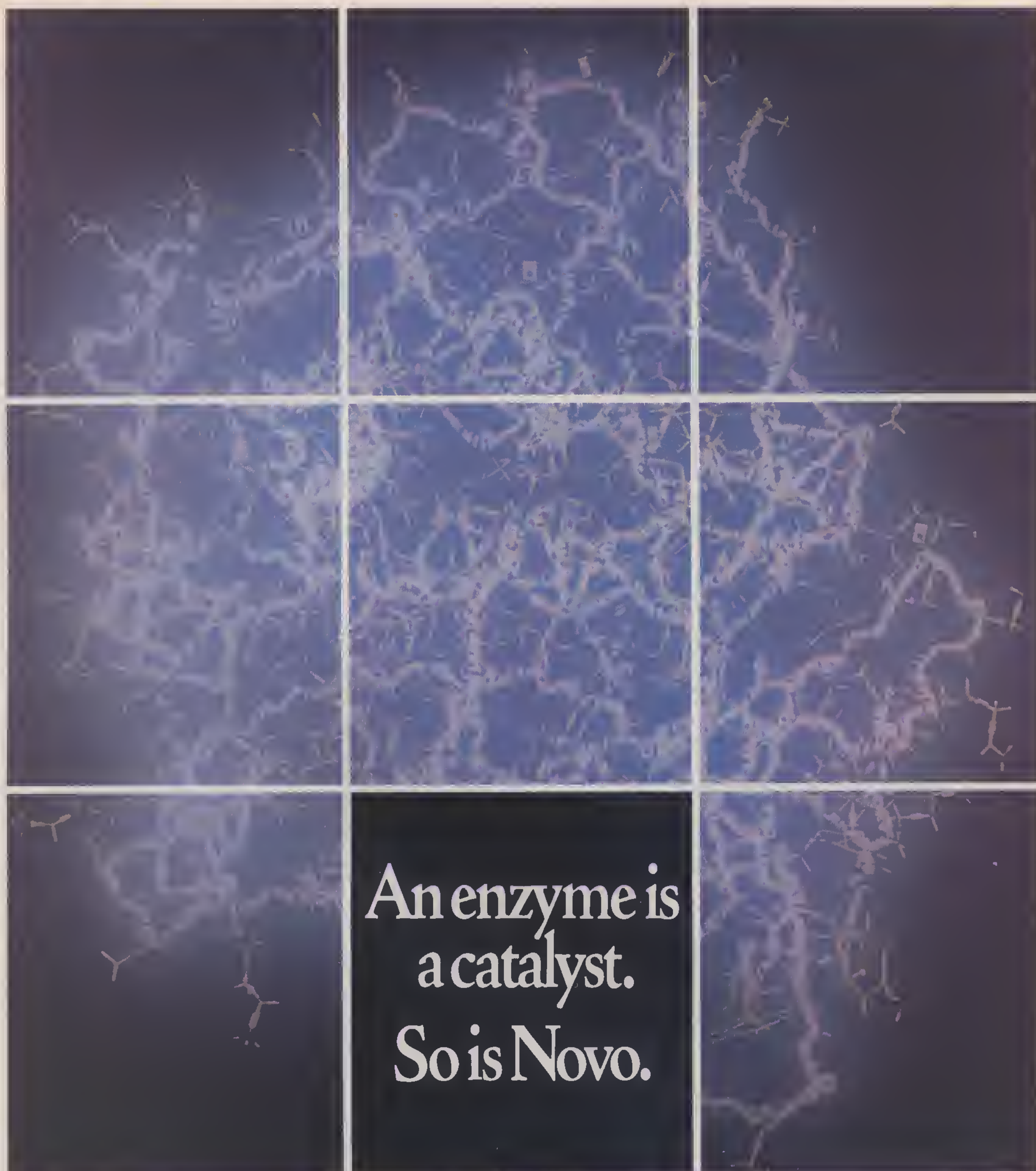
These advanced processors will enable researchers to predict how a few amino acid substitutions will alter the known crystal structure of a protein. But predicting a protein's entire folding pattern from its amino acid sequence alone is a formidable problem that will likely remain unsolved for the foreseeable future. The reason is that evolution has optimized protein structure for many different factors, of which a stable folding pattern is not always the most important. Computer programs for predicting a protein's folding pattern on the basis of its amino acid sequence will therefore probably be based on a best-fit comparison with a large library of known protein structures.

An expert system to help with the structure prediction process is being developed at the University of California at San Francisco by Robert Langridge, head of the Computer Graphics Laboratory, and chemistry professor Irwin Kuntz, Jr. Using a specialized computer for running artificial intelligence programs and a "friendly" programming environment, the team is developing rules for predicting turns and secondary structure (that is, either the alpha helix or the beta pleated-sheet pattern) from the primary amino acid sequence. They then plan to use computer graphics to predict how this secondary structure folds up into the active form of the protein. The UCSF researchers hope that this approach will make it possible to winnow out all but a limited number of probable conformations, which will then be subjected to conventional energy-minimization analysis.

As a technology, protein engineering is clearly still in its infancy, and most of the accomplishments scored thus far—the scientific verification of design methods and the demonstration that new proteins can be created—are unlikely to rank as major commercial breakthroughs. But they represent an auspicious beginning. "Protein engineering is at the same point in its development that genetic engineering was a decade ago," says Kevin M. Ulmer, director of the new Center for Advanced Research in Biotechnology (Rockville, Md.). "Although we still lack specific design rules, the basic concepts have been proved, the necessary equipment and techniques are in place, and the commercial potential can readily be identified." □

Jonathan B. Tucker is a former senior editor of HIGH TECHNOLOGY.

For further information see **RESOURCES**, *p. 69.*



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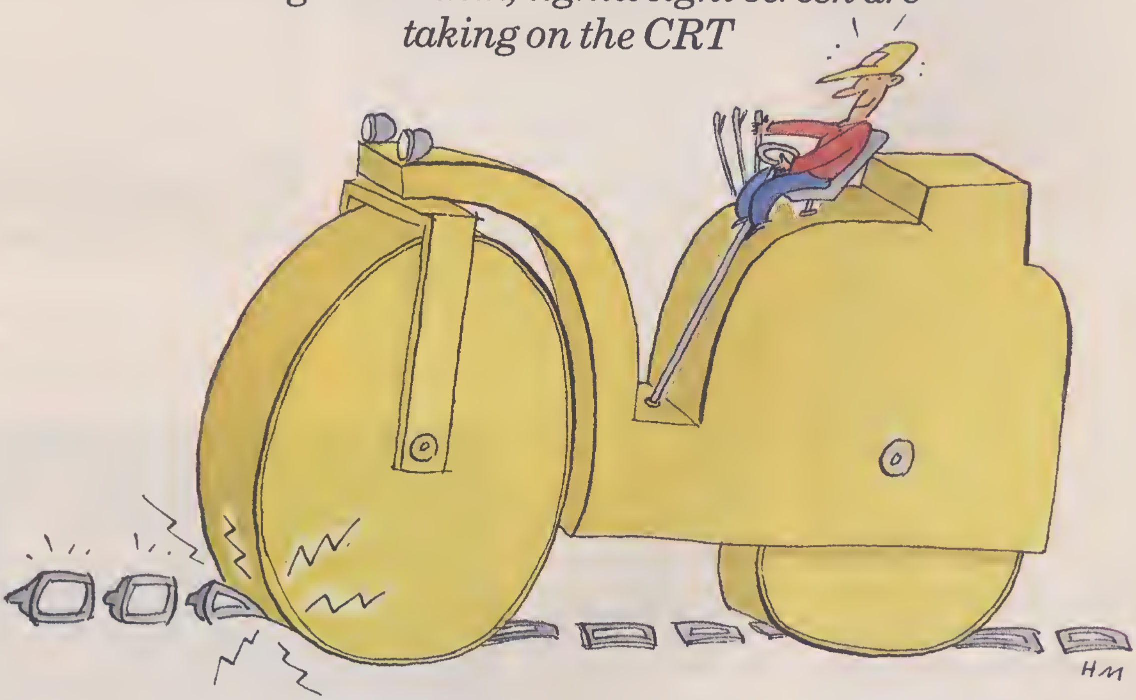
THE FLAT PANEL CHALLENGE

Display technologies that can put vivid images on a thin, lightweight screen are taking on the CRT



A flat electronic display without the bulkiness and power demands of the cathode-ray tube seems to have been just over the research horizon since the advent of the CRT itself. Finally, after years of promises and development, flat panels are just entering commercial use.

Eventually, an efficient flat panel technology might lead to a large television screen that can be hung on the wall and moved about at will. But TV is among the most challenging of display tasks; viewers accustomed to CRTs demand large, crisp, full-color pictures that depict motion without blur. Because the first flat panels cannot meet all these requirements, they are going into computer screens and small static displays instead—applications where resolution can be lower and color is not essential.

Even without TV, flat panels could grow to be a big business if generally adopted for battery-powered personal computers. In the past, battery power has meant limiting computational ability and screen size, making portable computers little more than souped-up calculators. But advances in flat display technology are making it feasible to construct full-size terminals. The two technologies emerging as the leaders are liquid crystals (using a technique known as active matrix addressing) and electroluminescence. Meanwhile, CRT manufacturers are working to produce flatter electron-beam systems in order to compete with the newer technologies.

HAL MAYFORTH

LCDs: a bright new face

by Hugh Aldersey-Wiliams

Already ubiquitous in watches, calculators, and other small electronic gadgets, liquid crystal displays (LCDs) are the most mature of the flat panel technologies. LCDs emit no light of their own. Instead, an electric field causes the liquid crystal molecules to line up in a way that alters their optical properties. In one molecular arrangement, light is reflected to give a picture element, or pixel, that is pale; in the other, it is absorbed to show dark.

Market forecasters say LCDs will remain popular through the end of the decade. By 1992 they will account for about 40% of what will by then be a $1-billion-a-year flat panel display market, predicts Stanford Resources (San Jose, Cal.). Another study, by Frost and Sullivan (New York), forecasts that by the same year 29% of portable computers sold will have liquid crystal screens.

These rosy projections assume considerable technical improvement. Because of their poor contrast and viewability, LCDs have so far made few inroads into large-screen applications. These afflictions should largely disappear, however, with the advent of new techniques for activating the display.

In present LCDs, electrical signals are fed into row and column electrodes to trigger a reorientation of the liquid crystal molecules at the intersection. A whole row of the display is activated with a voltage just below the threshold needed to effect the change. A small additional voltage is applied to those column electrodes corresponding to the pixels in the activated row that are to be switched on. The process is repeated for each row to fill the whole display screen, a technique known as multiplexing.

However, the influence of row and column electrodes extends beyond the intended pixel at their intersection; as a result, signals meant to make one pixel black also affect neighboring pixels. This is why today's common LCDs are not so much black and white as dark gray and light gray. Moreover, contrast deteriorates as display size increases. With greater numbers of electrodes crisscrossing the liquid crystal, the voltage spilling onto pixels meant to be "off" starts approaching the switching threshold.

The first product to incorporate a full-screen multiplexed LCD was the Data General/One personal computer introduced in September 1984 by Data General (Westboro, Mass.). With resolution of 640 × 200 pixels, the screen can display IBM PC software. This allows Data General to claim full PC functionality in combination with battery operation and true portability.

Though a pathbreaking development, the Data General/One is a prime example of how the poor image quality of large LCDs has held back their widespread acceptance. Its contrast ratio is only 3:1, making the screen hard to read. Moreover, it must be viewed head-on, and both the user and the light source must be carefully positioned. Soon after the Data General/One's debut, Apple Computer (Cupertino, Cal.) released a flat panel version of its IIc personal computer. The Apple LCD resolution of 560 × 192 pixels is coarser than Data General's, but it matches that of the CRT version of the IIc.

Some dramatic improvements in LCDs are possible with an alternative to multiplexing known as active matrix—or active substrate—addressing. In this scheme, a semiconductor switch is deposited everywhere that a row and column electrode intersect (that is, at each pixel). Such switches have a sharp turn-on threshold; thus signals applied through the electrodes affect only the intended pixel.

The active substrate is deposited directly onto the glass sheet that will form the rear plate of the display cell. The thin substrate is transparent, allowing the display to be illuminated from behind, giving a closer resemblance to a CRT than conventional reflective LCDs do. Backlighting also makes possible a color display, which is achieved by depositing a tiny red, green, or blue filter on each pixel. (Color LCDs viewed solely with ambient light do not have sufficiently good images for use either as televisions or as color terminals.)

The most common active matrix switch is a thin-film transistor (TFT), which consists of three parts: a source, a drain, and a gate. In a TFT display,

JOHN TROHA

Panelvision's active matrix LCD screen, shown by marketing VP Thomas C. Maloney, is backlit to increase brightness.

column electrodes are connected to each transistor's source, and row electrodes to each gate. When a voltage is applied to both the gate and the source of a particular transistor, charge passes to the liquid crystal via the drain, activating the pixel. TFTs receiving a signal only at the source or only at the gate are not switched. A TFT thus allows more precise addressing of individual pixels, greatly enhancing image contrast.

Other designs are also possible. Metal-insulator-metal (MIM) devices, for example, are being pursued by Suwa Seikosha (Seiko) for its LCD televisions and by Commodore for portable computers. MIMs have resistance that varies with applied voltage. The small "off" voltage encounters a high resistance; the low resistance at the "on" voltage lets charge pass to the pixel electrode. MIMs are simpler to fabricate than TFTs, requiring fewer deposition steps; so far, however, high cost and low reliability have blocked commercial use.

In another scheme, Citizen Watch places at each pixel two diodes that pass current into the liquid crystal and then seal the charge in place. The device turns on at a lower voltage than either a TFT or a MIM; this feature yields a comparatively large span of usable signal levels between threshold and the maximum voltage at which the device can function. Because of this wide operating range, Citizen's display readily generates shades of gray, a must for TV applications. In addition, the two-diode scheme has a sharper threshold effect than other active matrix devices, making it easier to single out a particular pixel in a large display; Citizen says a 5000-line LCD is possible.

The only U.S. company now marketing an active matrix–addressed display is Panelvision (Pittsburgh), a Westinghouse spinoff that was acquired in June by Litton Industries. "We strongly believe that in the next decade active matrix–addressed displays using arrays of thin-film transistors will become the solid-state analog of the CRT," says marketing vice-president Thomas C. Maloney.

The central issue facing active matrix developers is the choice of material. The ideal material could be deposited easily and uniformly over a large panel and would conduct electricity fast enough that the substrate could incorporate all the display's "drive" electronics. All the materials being tested are compromises.

Single-crystal silicon has been used

Pocket-size TVs are an early use of active matrix LCDs. A thin, transparent substrate allows backlighting for a bright color display.

in some early prototype LCDs, but its future appears limited. While its "carrier mobility" (the speed at which charge moves through it) is very high, large single-crystal wafers are tough to grow. In addition, the wafers' thickness and resulting opacity rules out backlighting. The only major commercial implementation of single-crystal substrates has been a wristwatch-size TV introduced in 1982 by Suwa Seikosha.

For most other applications, however, the semiconductor must be easier to form over larger areas. Suwa Seikosha turned to polycrystalline silicon (polysilicon) for a more recent LCD project: a 100-mm-diagonal color television with 480 × 480 pixels. Polysilicon has much lower mobility than single-crystal silicon; however, it can be deposited in a thin, transparent film to permit backlighting for a more attractive, luminous image.

The material used in most active matrix LCD panels is amorphous silicon, which can be deposited uniformly over large areas. Two U.S. companies—Ovonic and Alphasil—are developing amorphous silicon technology for displays. Both are spinoffs of Energy Conversion Devices (ECD—Troy, Mich.), which pioneered applications of the material, particularly for solar cells.

Ovonic (Ann Arbor, Mich.) will start producing PC-size LCDs by year's end, says Zvi Yaniv, vice-president for engineering. Amorphous silicon's major shortcoming—low carrier mobility—does not disturb Yaniv. The material is fast enough to allow integration of drive electronics at the 30-frame-per-second video update rate, he maintains. Moreover, he says, innovative semiconductor structures could yield "dramatic" performance improvements; for example, shortening the TFT's gate region from the standard 10 microns to about 1 micron would multiply by 100 times the maximum screen-update frequency.

Alphasil, a start-up in San Ramon, Cal., is also looking to develop a large-scale LCD panel using amorphous silicon. The company is moving into pilot production of a 200-mm-diagonal panel with 480 × 250 pixels. The first application will be in specialty military systems that require a compact, rugged, low-power display. But a PC-compatible panel may follow. Alphasil deposits a TFT at each pixel but simplifies fabrication by cutting the number of deposition stages to four, says Alphasil cofounder Richard Flasck (ECD's solar cells require six).

Amorphous silicon is already widely used in Japan. Sanyo, Casio, and Citizen Watch have all demonstrated miniature LCD television sets using active substrates of the material. But the sets' resolution is considerably lower than the standard of 525 lines.

General Electric (Schenectady, N.Y.), which had been working with zinc oxide devices, has joined the growing band of amorphous silicon devotees. The company has built a 200 × 200–pixel panel measuring 50 mm square. Unlike most other LCD panels, the GE product is targeted to a particular niche: aircraft instrumentation. It is not, the company insists, a prelude to an LCD television or computer terminal.

Panelvision's display does not use silicon at all but rather cadmium selenide (CdSe). The company recently announced a 640 × 400–pixel prototype, and already markets a 192 × 128 panel. The product has not gone into large-scale production; Panelvision now turns out around 500 units per month and prices them at $750—ten times as much as a CRT.

Cadmium selenide provides higher carrier mobility than either amorphous or polycrystalline silicon yet does not entail the exacting processes required for single-crystal structures. The deposition process for the TFTs that drive the panel is more complex than amorphous silicon techniques, however, and is thus said to be more prone to variation and low yields. Still, Panelvision believes that cadmium selenide is superior to amorphous silicon and polysili-

con for fabricating high-performance, high-speed displays. And unlike most other LCD makers, Panelvision is working toward integrating all the display circuitry onto the display substrate. "The goal," says Maloney, "is to compete with the CRT functionally and economically."

That, of course, will require dramatic reductions in cost, which the company believes will come with larger-volume production. In the meantime, Panelvision is focusing on a market where cost is not the paramount concern: the military. First use will probably be in aircraft instrument panels; Paul Malmberg, manager of systems engineering, says the Panelvision LCD's compactness and high readibility in sunlight give it a considerable performance advantage over CRTs. □

Hugh Aldersey-Williams is a New York-based technology writer.

For further information see **RESOURCES**, *p. 69.*

Electroluminescence: better picture, higher cost

by Gordon Graff

The electroluminescent (EL) panel, once an also-ran in the competition for flat computer displays, is finally hitting its stride in the marketplace. Not only is it challenging the CRT, but it is giving its old nemesis, the cheap but hard-to-read liquid crystal display (LCD), a run for its money as well.

With their pleasing amber radiance, light weight, and thin profile, EL displays have already made their debut in a few portable computers. And while no one expects EL screens to make museum pieces out of the CRT or LCD, they are expected to carve out a tidy niche by catering to consumers willing to pay a premium for portable computers that are both readable and compact.

The market for "large-area" (computer-size) EL displays, which was essentially nonexistent three years ago, is on the order of $20 million, estimates Charles M. Apt, an electronics specialist with Arthur D. Little (Cambridge, Mass.). As computer applications grow and prices come down, says Apt, markets for the displays will soar to $190 million by 1992. While computer displays will account for most of this growth, automobile dashboards and medical, military, and process-control instruments will also be outlets. These forecasts have been sharply scaled down from those made as recently as a year ago; the current downturn in the personal computer business "is really retarding everything," says Apt.

Downturn or not, producers of EL displays—the major ones are Sharp in Japan, Planar Systems (Beaverton, Ore.), Finland's Lohja, Sigmatron Nova (Thousand Oaks, Cal.), and Britain's Phosphor Products—believe their displays' inherent advantages will be strong selling points.

For one thing, EL displays are "active," emitting their own light rather than passively reflecting light as do LCDs, so they can be viewed under almost any lighting conditions. ELs also have higher contrast, better resolution, and much wider viewing angles than LCDs. In addition, EL displays are far less bulky and heavy than CRTs. A typical EL computer display, including associated electronics, is less than an inch thick and weighs about a pound.

On the debit side, EL displays consume far more electrical power than LCDs. An EL screen of 25 lines of 80 characters, for example, uses about 15 watts—roughly 100 times as much as an LCD of the same size—ruling out battery operation. Also, the high fabrication costs of EL panels have kept their prices (now $500–$700 in bulk quantities) more than twice those of comparable LCDs.

Yet there are technological developments on the horizon that will add to the EL flat panel's luster—literally. These include the advent of full color, new high-contrast designs that make the displays readable even in sunlight, and advanced driver electronics that make the panels more compact and energy-efficient. Meanwhile, economies of scale are expected to trim unit cost to as low as $300 in the next two years.

While work on EL displays dates back to the 1950s, they were not considered commercially viable until 1974, when Sharp demonstrated a design called the AC thin-film electroluminescent, or ACTFEL, display.

For most of the past decade, low fabrication yields and resultant high prices kept the EL display on the shelf. But recent interest in portable computers has spurred renewed development work.

The heart of an EL display is a light-emitting layer of phosphor, usually consisting of zinc sulfide doped with manganese. The phosphor is sandwiched between two sets of electrodes, one forming rows and the other forming columns. (A full-screen computer display with 25 lines of 80 characters typically consists of 256 rows and 512 columns.) Placed between the electrodes and the phosphor is an insulating layer that helps prevent burnout at the 200

or so volts needed for operation.

Images on a screen comprise thousands of dots of light formed by the phosphors at the electrode intersections. The electronic drivers that control the display address a whole row at a time. As each row is addressed, the drivers send charge to some columns and not to others, depending on the image to be displayed. When the additive row/column voltage at a pixel (picture element) exceeds a threshold value, the phosphor glows; otherwise the pixel remains dark. Above the threshold, increased voltage makes the phosphor glow proportionately brighter; thus a gray scale is possible. A standard EL display addresses each row 60–64 times a second—fast enough to avoid flicker, but slow enough to allow the pixels to respond.

Making an EL panel is straightforward, but the thin phosphor film must be deposited with extreme precision; a dust particle falling on the phosphor during manufacture can cause a concentration of electrical charge at that site, short-circuiting the pixel. As many as 70% of the displays in some production runs have been defective, although defect rates have recently been improved to as low as 30%.

While Sharp and Planar Systems lay down the phosphor by means of a well-established spraying technique called sputtering, Lohja is pioneering its own method, called atomic layer epitaxy. A heated substrate is exposed to compounds bearing the elements that are to become part of the film. These compounds decompose, and their constituent atoms deposit on the substrate one layer at a time. The result is a very thin, uniform layer of phosphor on the substrate, says Ulf Strom, president of Finlux (Cupertino, Cal.), Lohja's U.S. subsidiary. The thin film gives a brighter display, he explains, because the light emitted by the phosphor does not have to travel through layers of nonemitting phosphors.

Both Sharp and Planar Systems supply 25-line, 80-character EL displays for portable computers from Grid Systems (Mountain View, Cal.); the Grid Compass weighs 11 pounds and fits on a lap. And Sharp's 25 × 80 EL display allows Hewlett-Packard's Integral portable to put all the features of a standard office computer in a 25-pound package. In addition, Data General reportedly is switching from liquid crystal to electroluminescence on its Data General/One personal computers. Partly because of the power-hungry ELs, however, all three computers must be plugged in.

Slim electroluminescent panel stands in dramatic contrast to a standard CRT.

Hewlett-Packard's Integral computer sports a 25-line, 80-character-per-line EL display. The display's high power consumption rules out battery operation, limiting portability.

Computers are not the only commercial market for EL displays. Finlux, for example, is developing panels to display a page of medical tables, charts, graphs, and other data on compact diagnostic instruments that could easily be moved from one hospital room to another. And both GM and Ford are developing computer-linked EL road map displays for dashboard-mounted navigation systems. The driver simply enters starting-point and destination data, and the system calculates the shortest route, indicating the car's progress on the screen.

Meanwhile, the military—one of the earliest customers for EL technology—continues to be interested, primarily because of the panels' solid-state ruggedness, low power consumption (relative to CRTs), and good viewability. For example, Planar Systems is building a 3 × 5–inch display for a U.S. Army portable field terminal.

Present ELs are monochromatic. But "everyone is working on color," says David Mathews, national sales manager of Sharp Electronics (Paramus, N.J.). Planar Systems

The CRT fights back

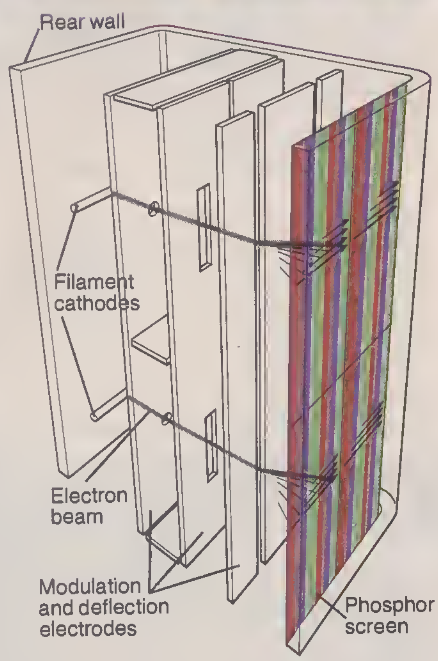
Makers of cathode-ray tubes are challenging the arrival of flat panels by compressing the CRT design and cutting its power needs. The first flat-screen CRT television to reach the market was the Sony Watchman, which now presents a 100-millimeter-diagonal screen. The Watchman uses two deflection circuits, just as a conventional CRT does, to move the beam vertically and horizontally. But the beam strikes the phosphor at a shallow angle rather than head-on, allowing the tube to be flattened. Moreover, the power requirement is lower, because the picture is viewed from the side of the phosphor that the electrons strike. With a conventional CRT, the picture is viewed through the thickness of the phosphor layer, which is struck from behind; more power is needed for the glow to penetrate the layer to give a bright picture.

A larger (300-mm-diagonal) flat CRT has been demonstrated by Philips at its research labs in Great Britain. The display waits until the last moment to boost the electron beam's current. The unamplified beam can be made to travel back and forth parallel to the screen before it is turned toward the phosphor; this "folded" beam path allows the electrons to be scanned across a screen width that would otherwise require the depth of a conventional CRT. The design reduces power consumption, too, because less energy is needed to manipulate a low-current beam. A color version is now being studied. Current thinking favors a concentric "target" pattern of red, green, and blue phosphors. Fine focusing would give the red of the bull's-eye, and increasingly diffuse focusing would excite the green and blue phosphors. (The center red phosphor would also be hit, but its small area would reduce its effect on the hue.)

RCA, the largest U.S. maker of televisions, has developed a flat display that uses a shadow mask and color phosphors just as in a conventional TV. Electrons are produced from a line source rather than a gun. The electron beams are guided along striplike modules and diverted toward the phosphor by electrodes at the pixel to be hit. About 30 modules, each 30 × 740 mm, make up a 1.25-meter-diagonal screen.

RCA's goal was to develop the guided beam display for use in high-definition television, which will have more than double the number of scan lines used in today's sets, to give "photographic-quality" pictures. But now, says Tom Credelle, head of the flat panel display project at RCA Labs (Princeton, N.J.), RCA is not sure that the technology can reach that high a resolution. The flat CRT has been put on the back burner and attention turned to LCDs.

ETHAN HOFFMAN/ARCHIVE



Matsushita's 2.5-inch-thick CRT uses 3000 separately controlled electron beams to scan the screen in many small portions.

Japan's Matsushita, meanwhile, has incorporated many of the RCA ideas. The company has announced a prototype 250-mm-diagonal color flat panel television with half the number of scan lines of today's sets (HIGH TECHNOLOGY, July 1985, p. 6). The tube produces 3000 electron beams, each scanning a small area of the display screen. Matsushita's panel uses more electron sources and less deflection than RCA's, and Matsushita's fine-focusing system avoids the need for a shadow mask.

Siemens of West Germany and Lucitron (Northbrook, Ill.) have gone the farthest from the traditional CRT. They use no electron beams at all; instead, an electrical discharge in a gas produces an electron cloud over the entire screen area. In front of the layer of activated electrons is a control plate with row and column electrodes.

In the Siemens scheme, electrons are squirted through the 300,000 tiny holes in a thin ceramic control plate. At points where the screen is to be lit, an accelerator plate provides energy to the electrons so they can excite the phosphor. Column electrodes govern the number of electrons that pass through the holes, giving the panel a gray scale. Siemens has built a 448 × 720–pixel prototype.

Lucitron's panel, dubbed Flatscreen, works similarly. However, it extracts electrons from numerous "plasma sacs," each generated over a small part of the display. The company cites several advantages. The small plasma sacs concentrate the electron current, producing a brighter image. Electronics can be simplified, too; the 254 × 352–pixel prototype needs only 10 row drivers and 16 column drivers. Moreover, the well-contained sacs permit the display to contain internal walls, providing the structural support necessary for screens as large as four square feet, says Lucitron VP Alan Sobel.

—Hugh Aldersey-Williams

has a $1.5 million Army contract to develop a full-color EL display, and president Jim Hurd says the company is interested in developing color screens for consumers as well.

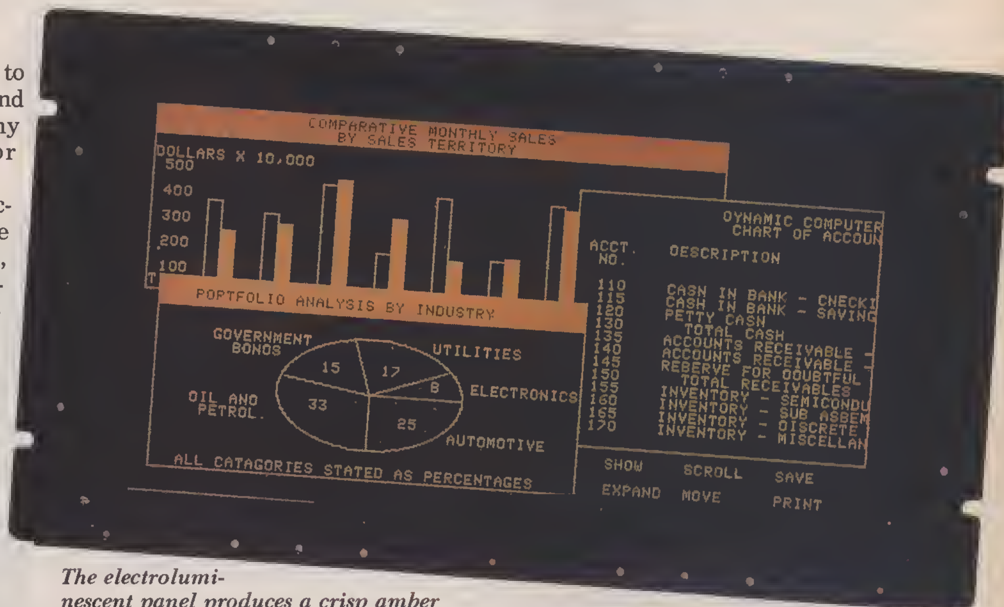
The leading technique for introducing color involves depositing three phosphor layers—one that glows red, one green, and the other blue. A separate matrix of row and column electrodes addresses each layer, and the relative intensity of these primary colors at each pixel determines the hue that is seen.

One problem with this approach is that the driver electronics become unwieldy. Another complication: The red and blue phosphors do not glow with the same efficiency as the green phosphors, making it difficult to achieve correct color.

Planar is trying to make the red and blue phosphors brighter by addressing them more often than the green phosphors. But this solution adds to the already considerable complexity of the driver circuitry.

Indeed, says Hurd, "there's a whole set of electronic addressing issues that have to be worked out" before color can become feasible.

To reduce the size and weight of a panel, engineers would like to build the driver electronics into the display instead of placing them externally, as is done now. The obstacle has been that ordinary semiconductor chips cannot handle the high voltages used in electroluminescent displays.



The electroluminescent panel produces a crisp amber image that is well suited to computer displays.

Recently, however, Planar Systems has incorporated into its displays a driver system consisting of a newly developed "smart-power" integrated circuit that can switch much larger currents and voltages than a typical IC. The chip, supplied by Texas Instruments (Dallas), consumes far less power than the bulky and heavy circuit board it replaces.

Trimming power requirements is only one goal of EL developers. Another—of particular importance in military field applications and in avionics—is to make the panels more readable in sunlight. The polarizing filters that are now used to block glare also cut out as much as 65% of the display's illumination and greatly reduce viewing angles. Recently, both Lohja and Sigmatron Nova have made their displays viewable in sunlight by incorporating a light-absorbing substance into the panels, darkening the background and thus heightening contrast.

But EL makers regard high-contrast displays for military field instruments and airplanes as a fringe market; it is still the computer sector that companies are eyeing with eager anticipation. And they've pretty well staked out their likely customers. Planar Systems' Hurd thinks there is a pent-up demand for a computer that could serve as both a desktop unit in the office and a portable on the outside.

"We want to shrink the volume of a CRT-based desktop by well over an order of magnitude" without sacrificing performance, Hurd says, adding that the EL display is ideally suited to such downsizing.

Hurd, like the rest of the EL community, is looking primarily at the well-heeled business user. "Most people don't want to pay for a desktop and a portable," he says, "but I think they'd pay a premium if they could use one unit with both capabilities." □

"We want to shrink the volume of a desktop computer by an order of magnitude," says Jim Hurd, president of Planar Systems, the major U.S. maker of electroluminescent panels.

RICH IWASAKI

Gordon Graff, a New York freelance writer, is a former senior editor of HIGH TECHNOLOGY.

For further information see **RESOURCES**, *p. 69.*

BUSINESS OUTLOOK

Large-area flat panels hitch a ride on portable computers

Domestic sales of large-area flat panels—displays containing more than one line of 20 characters—are expected to reach $155 million this year, according to Frost and Sullivan, a New York–based market research firm. This figure, which is 31% of the dollar volume of all flat panels sold, should rise to $680 million (50%) by 1990.

Large-area flat panels are predominantly used in briefcase-size portable computers intended for salespeople and other frequent business travelers. These machines weigh 8–12 pounds, in contrast to "transportable" computers that generally use CRT screens and weigh 25 pounds or more. Up to 90% of these portables are battery-operated computers employing liquid crystal display (LCD) technology—a percentage that Frost and Sullivan expects to remain constant over the next five years.

Production of large LCD panels for the U.S. market is dominated by such Japanese giants as Sharp, Epson, Seiko, Hitachi, and Toshiba. Hamlin (Lake Mills, Wis.) is the only U.S. manufacturer of LCDs to achieve as much as a 15% domestic market share, although Panelvision (Pittsburgh) has developed proprietary LCD technology aimed at such niche markets as military instruments and avionics. A standard-size (25-line-by-80-character) LCD costs some $200, about three times as much as an equivalent CRT display.

Most of the non-LCD portables use electroluminescent (EL) flat panels, whose power requirements necessitate plugging the computer in. EL is likely to appeal to a "fringe market, consisting of people willing to pay a premium for high-quality flat-screen portables," says David Mathews, national sales manager of Sharp Electronics (Paramus, N.J.), which makes both LCD and EL displays. Other participants in the EL market include Planar Systems (Beaverton, Ore.)—a major player—Finland's Lohja, Britain's Phosphor Products, and Sigmatron Nova (Thousand Oaks, Cal.).

EL computers, made by such companies as Grid Systems (Mountain View, Cal.) and Hewlett-Packard (Palo Alto, Cal.), go for $3000–$7000, versus $2500–$3000 for an LCD machine of equivalent capabilities. However, the price of EL computers could come down as the displays drop from around $600 to $300 over the next few years, says Mathews. A third technology, gas plasma flat panels, has not yet been widely used in computers, but Grid features such a display in one product line, as does Panasonic in one of its new computers and in a unit it builds for Ericsson.

Future growth of large-area flat panels depends on a reciprocal relationship with portable computers. Advances in display technology should improve the appeal of portables, while any increase in portable sales would accelerate demand for displays. According to Sol Sherr, president of the consulting firm Westland Electronics (Hartsdale, N.Y.), sales of portables have risen from $135 million in 1983 to an estimated $200 million this year, limited by their high prices and by the slowdown in demand for personal computers. "You really have to have special needs to warrant the extra cost of a portable when you already have a desktop personal computer," says Gunther Rudenberg, a consultant with Arthur D. Little (Cambridge, Mass.).

But Rudenberg predicts that technology will ultimately revive the market for flat panels—and for portable computers—by making the panels easier to read and lower in price. For example, he says, the common LCD problems of low contrast and narrow viewing angles may be solved by the development of "active matrix" displays, in which thousands of tiny transistors boost image quality by giving an extra jolt of electric charge at each pixel (picture element). And he believes that the gradually falling costs of the integrated circuits that control LCD flat panels will contribute to lower overall display prices.

Active matrix displays are already beginning to show up in some products with small screens, such as a pocket television produced by Epson. The big challenge, says Westland's Sherr, is to reduce the defect rates in the manufacture of large-area panels. He estimates that if the costs of LCD and EL panels continue to drop, the portable market could grow from $200 million at present to at least $2 billion by 1990.—***Gordon Graff***

"It would be hard for a small company with a proprietary technology to match the huge marketing power of Japanese firms in the flat panel field. It could succeed only by working out a marketing arrangement with a large computer manufacturer such as IBM."

Tim Riggins
Analyst
Future Computing

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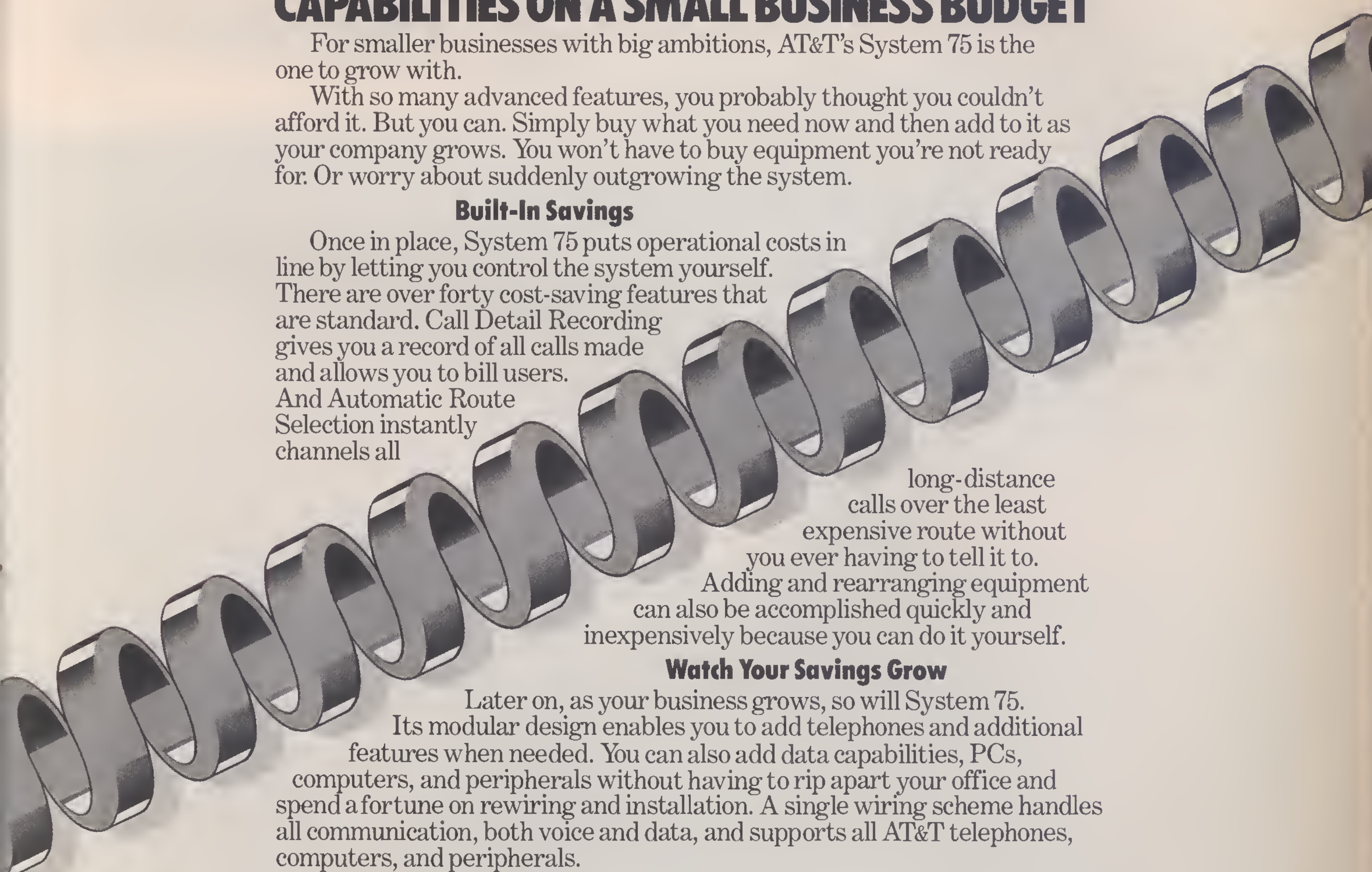

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Sometime within the next ten years or so, a Nebraska farmer will switch on his TV and settle back for the evening while his new assistant tends the weeds on the back forty. Chugging down rows of crops, the assistant—a computerized, radar-controlled vehicle fitted with a machine vision system, a pump, and a few gallons of herbicide—stops briefly at a clump of vegetation to analyze its shape and complexity. If the image is substantially different from that of crops stored within the computer's memory, a signal goes out to the pump and a preset burst of liquid is delivered to the doomed plant.

The automated weed killer is just one example of the "smart farm machines" that may be working on some American farms by the end of this decade. These systems, together called "prescription farming," aim to boost U.S. agriculture's productivity and to reverse declines in its international competitiveness. Also included are irrigation and fertilization based on networks of computers and sensors. Robotized harvesters, automated animal-control devices, and food handling and processing equipment are nearing trials.

"The challenge now is to develop these machines, which consider every variable as you go down the field and make the necessary adjustments," says James Anderson, dean of agriculture at Michigan State University (East Lansing) and past president of the American Society of Agricultural Engineers.

The notion of fully automated farms—in which robotic tractors traverse fields day and night, in good weather and bad, sensing variations in field conditions and automatically correcting for them—is not as fanciful as it sounds. "The technology is here," says Ralph Nave, national program leader for energy and engineering at the U.S. Department of Agriculture's Agricultural Research Service (ARS—Beltsville, Md.). "Being able to accurately locate the tractor or combine in the field is probably five years away."

Such devices alone, of course, will not solve most of the basic problems now facing American farmers—persistent crop surpluses, the strong U.S. dollar, and heavy personal debts incurred during the expansionary late 1970s and early 1980s. There is also some question as to how many small and medium-size farms (many of which are already facing bankruptcy and foreclosure) will be able to plug into the new technology. For the survivors of the inevitable shakeout, however, prescription farming may be an important key to improved efficiency and lower costs during the 1990s.

How much water? Much of the technology focuses on controlling one of the most important

MICHAEL MELFORD

of all farm resources: water. Using new methods of measuring it and turning it on and off only as needed, prescription farming could dramatically reduce water consumption and make every drop count, especially in areas in which water is steadily being diverted to nearby urban populations. And by extending water-sensing techniques to fertilizer control, smart farm machines could protect the drinking water supply by limiting the amount of fertilizers used, thus preventing residues from accumulating in the groundwater.

Conventional irrigation-monitoring systems use timers or measures of water flow—indirect indicators of the amount of moisture in the soil. Moisture must then be calculated using estimates of average rates of evaporation and transpiration. Whenever actual rates differ from the average, the wrong amount of water is delivered.

A sensor-based system for monitoring soil moisture has been developed by Richard Miller, a professor of electrical engineering at the University of Central Florida (Orlando) and senior engineer for Agri-Comp (St. Cloud, Fla.). Because the sensors have not yet been patented, he will say only that they are electromagnetic and run on a 9-volt battery charged by a 4 × 7–inch array of solar cells.

Miller compares the sensor and its associated electronics, computer, and controls to a home heating system. "You set your thermostat and the system controls the temperature of your house," he says. "Our computer checks the soil moisture through a sensor and controls the irrigation system to keep the soil moisture in a preset range. It has the potential to do the same thing with fertilizer."

The system consists of two soil moisture sensors for each irrigation valve. "The sensors will be placed in the area controlled by the valve," Miller explains. The signals from the sensors are transmitted to a central control facility on fiber optic cables, chosen because they reduce the risk of lightning damage and electromagnetic interference. The information is passed through a specially developed signal processor, then converted to digital form for transmission to a computer. An Atari 800 XL was used for development, but a custom

AUTOMATING AMERICA'S HEARTLAND

Robot vehicles and electronic irrigation could help keep costs down on the farm

by Paul Raeburn

board designed around an Intel 8080A chip will be used in the prototype.

The computer runs customized software with information on the variety, age, configuration, and root depth of trees, the types of soils and their locations, the irrigation system, seasonal weather data and five-day and 24-hour forecasts, and anticipated prices and production costs. The decision to irrigate is based on analysis of all these variables.

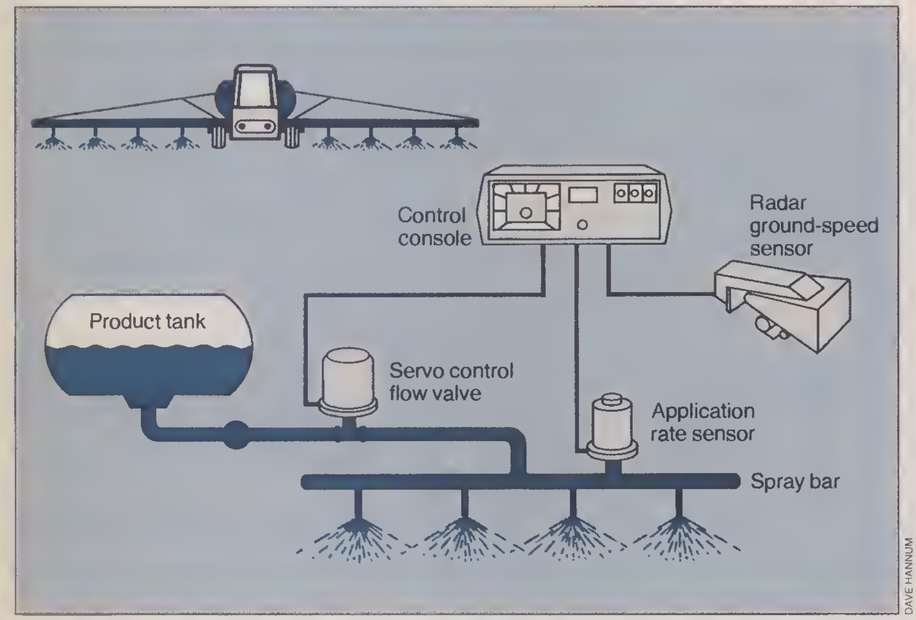
"In recent years, farmers used about 40% of all the water available," says Miller. "As the population of the cities goes up, there's going to be a lot of pressure on farmers to use their water more efficiently." Furthermore, he says, citrus growers face increased competition from growers in Central and South America who have considerably lower labor costs and can often export produce to the U.S. at prices lower than those of American farmers. Increased production efficiency—brought about partly by careful application of water and fertilizer—can help the growers meet that challenge.

"What we want to prevent is overwatering," says Miller. "Most grove owners don't have any problem knowing when they need to put on water, but a lot of them overwater." Pumps thus run longer than necessary, and excess water runs right through the root zone of the trees. What's more, water-dissolved fertilizer is carried into the underground aquifer.

The Agri-Comp system was slated for preliminary field tests in a Florida orange grove during the fall. If successful (and if a pending patent application is approved), the device could be on the market early in 1986. A relatively simple Agri-Comp network, consisting of computer, electronics, and several sensors of Agri-Comp's design, will probably cost $9000–$10,000, says Miller—"about the same as a pickup truck."

Although Agri-Comp designed the sensors for use in orange groves (the company's specialty), the market should be much broader than citrus, says Miller, because many areas share Florida's growing concern over a shortage of water as population increases. "The same system would work on turf farms [for sod production], golf courses, or for any crop that depends on controlled soil moisture," he says.

The system will soon be extended to monitor fertilizer concentration. "When the farmer sees that the corn leaves are turning yellow, signaling a lack of nitrogen, it's too late to replant," says Glen Vanden Berg, an agricultural engineer for the ARS in East Lansing, Mich. "We want to be able to make these assessments in a real-time, nondestructive manner, so we can put them back into the feedback loop to affect what's going on." The fertilizer sensor is based on the same principles as the moisture sensor, but will detect the soil's concentration of ions (charged chemical particles) from the dissolved fertilizer.



An automated sprayer system developed by DICKEY-john assures controlled liquid flow, even when tractor speed varies. The radar unit measures the actual ground speed, then relays the data to the control valve and application rate sensor to adjust the flow.

Water when it's needed. Another approach toward water control is being studied by Canadian researchers at UMA Engineering (Lethbridge, Alberta), a consulting firm. Their goal is an automated method whereby the farmer takes irrigation water as he needs it (just as in his home), rather than at the discretion of a district controller.

The problem in Alberta—and in many water districts in the western United States—is to control the flow of water through a branching network of irrigation ditches so that each farm gets the amount of water it wants at the right time. "A farmer may call the district to request water for 15 hours Thursday, and it's up to the district to figure out how to get him water for 15 hours—and only 15 hours," says Byron Palmer, UMA's director of research. "In some areas it's more constraining. They'll tell the farmer, 'You're going to get water this week, not next week, and for 15 hours—take it or leave it."

The Alberta system measures water depth rather than flow, using a computerized network of depth sensors, irrigation-gate position sensors, and solar-powered electronics at each gate. The depth sensors (pressure transducers consisting of small membranes mounted inside polyvinyl chloride pipe) are positioned in small wells dug beside the irrigation ditches. The wells are linked to the ditches underground so the water level in a well will be the same as the water level in the nearby ditch. The sensor is connected by cable to the upstream gate, where a small Sinclair/Timex computer processes incoming signals and controls the opening and closing of the gate. "You don't have to measure the amount of water going to a farmer," says Palmer. "All you're interested in is water depth."

As a result, no centralized control is necessary. District supervisors can check the condition of individual gates by telephone or radio link, or by means of a system that would monitor all the gates. This approach allows simpler programming at each gate and less maintenance, says Palmer. Communications links with voice synthesis will be able to telephone operators to warn of emergencies. Operators will make corrections remotely using the touch-tone buttons on a telephone.

Palmer and his associates, including Charles Burt of California Polytechnic State University (San Luis Obispo), are in the second year of a three-year research project sponsored by the Alberta provincial government. Last year an automated gate was successfully field-tested. Next year a prototype system with six automated gates will be installed in the field. "By the summer of 1987," says Palmer, "it should be commercially viable."

Palmer says the depth sensors cost about $300 each and the cost to completely automate a single irrigation gate will probably be about $1000; de-

pending on size, a complete irrigation system could consist of several dozen sensors. UMA is now negotiating for the design of a special microprocessor to be used at each gate. According to Palmer, the 1.2 million acres of irrigated cropland in southern Alberta contains 5000 to 6000 gates that could be automated with this system. The system will have several advantages over current manually operated irrigation systems. "One is to cut down on the delivery time of water to the farmer," says Palmer. "A farmer doesn't always know four days ahead of time that he's going to want water. The system should also virtually eliminate spills from the bottom end of the ditches." When the farmer shuts off his water, "that information will cascade upstream and shut off all the gates that need to be shut off."

Controlling animals. The control of farm animals is also yielding to automation. One example is the system called NOAH (Natural On-Line Animal Housing), developed by Stephen Herbruck of Poultry Management Systems (Saranac, Mich.). Herbruck tested NOAH on his own egg-laying hens—about a million of them.

NOAH is an outgrowth of an automated egg-counting system Herbruck began six years ago. The counting systems, of which 250 have been sold (for $30,000–$70,000), use as many as 1500 photodetectors to record the passage of eggs on conveyors. Up to 70 variable-speed motors govern the movement of the conveyors, thus controlling the flow of eggs to the processing plant. A large center like Herbruck's can produce some 700,000 eggs daily. Counting that many eggs manually is a full-time job for one or two people.

NOAH extends the system to control all aspects of egg production, including the hen house environment—lighting, feeding, water, and ventilation. "We control pretty well everything that needs to be controlled," says Herbruck. "Based on that, we can generate all kinds of reports right down to the cost of production. It's a tool we use to make us better managers."

As many as 2000 devices can be monitored or controlled, says Herbruck, including water-flow meters, feed-weighing devices, variable-speed ventilating fan motors, and thermostats. Monitoring feed is itself a formidable job. Nutritional levels must be adjusted very carefully to optimize egg production, and the amino acid composition of the feed is changed weekly. "Chicken nutrition is probably more sophisticated than human nutrition," says Herbruck. "Everything is balanced."

NOAH now operates on an IBM Personal Computer, but is outgrowing it and will probably soon switch to the IBM PC/AT. The cost of a system is between $40,000 and $80,000, depending on its size. Herbruck uses two at his poultry farm, and has sold two others to egg production centers in Florida and Ohio.

The selling job for feed management is a little tougher than for egg counting, where the payback is easy to calculate, says Herbruck. "In NOAH, there are so many more intangibles. How do you analyze management?" Herbruck keeps a remote NOAH terminal in his home, so he can check the feeding systems before he retires each night.

In Australia, where wool supplies 13% of export revenue, engineers have developed a sheep-shearing robot called Oracle and tested it in over 300 experiments since 1979. The machine (which is still in the testing stage) is equipped with a map of the sheep's body shape. This serves as a guide once Oracle has been moved into contact with a mechanically restrained animal.

The restraining device, itself part of the project, is designed to present sheep to the robot in various positions. A second-generation robot is now under construction, says its designer, research engineer Stewart J. Key of the University of Western Australia (Perth). Computer models suggest that shearing systems, at a cost of $45,000 to $67,000,

ANDREW SACKS

Automated egg-counter is displayed by production manager Mike Sanders and friends at Poultry Management Systems. Conveyor and photodetectors log 700,000 eggs a day.

BUSINESS OUTLOOK

Farm tech: a hard row to hoe

Technological advances are increasing the utility of tractors and combines for planting, harvesting, fertilizing, and irrigation. But prospects for vehicles with such high tech features as computer controls, sensors, and digital displays must be tempered because of the prolonged slump in farm equipment sales resulting from hard times in U.S. agriculture generally.

The North American market for farm vehicles and associated implements peaked at $5 billion in 1979. Demand has dropped ever since, with sales falling to $2.2 billion in 1984, according to tractor vendor Deere & Co. (Moline, Ill.). The Department of Commerce estimates that this year sales of large (over 100-horsepower) tractors and combines will total only one-third of the nation's current manufacturing capacity, and no one anticipates a dramatic turnaround. "We will stay at least 40% below the 1979 peak for the next ten years," says R. Gerald Saylor, manager of agricultural economic research at Deere.

Deere accounted for about 29% of all tractors and combines sold in North America last year, according to *Stark's Off-Highway Ledger* (Chicago), an industry newsletter. The second major player was J. I. Case (Racine, Wis.), whose parent company, Tenneco, recently purchased the agricultural equipment assets of International Harvester. This gave the expanded Case a 19% market share. Other major players are Ford Tractor Operations (Dearborn, Mich.), Kubota Tractors (Compton, Cal.)—which imports small Japanese tractors—and Massey-Ferguson (Toronto). At least half the dollar sales of tractors come from smaller-horsepower units imported from Japan and Europe. Remaining sales come from the over-100-hp machines, 80% of which are made by Deere and Case.

"Farmers are good businessmen. If you show them they're buying something that will pay for itself within a year, they'll take it."

Wendell Gottman
Manager of Product Planning
J. I. Case

Decreasing farm income and high interest rates are currently the primary factors undercutting equipment sales. Net income from farming dropped in real terms from $18.9 billion in 1950 to $8 billion in 1980, reflecting a squeeze between declining prices for farm products and rising prices for the goods and services farmers buy, according to a study by Battelle (Columbus, Ohio). A drop in exports has added to this problem; farmers this year will export only two-thirds of the corn, wheat, and soybeans they shipped overseas in the early '80s, due to the high value of the dollar and increased competition from abroad.

Moreover, farmers are accustomed to obtaining credit for major equipment purchases, such as a large tractor, which costs $35,000–$125,000, or a combine at $40,000–$110,000. But interest rates are at historically high levels at the same time land values have slipped up to 40% in some regions, leaving many farmers without enough equity to finance major purchases.

In spite of these conditions, there is still a big need for farm equipment. "It's a mature market, but many tractors wear out each year and new ones must be purchased eventually," says Wendell Gottman, manager of product planning for J. I. Case.

But who can buy these tractors? "The farmers who are under the greatest strain are those who made major investments in the late 1970s, when land values were relatively high," says Deere's Saylor. He adds that "these mostly medium-size farms aren't generating enough cash flow to meet debts. But about two-thirds of the large farmers are in relatively good shape. They will buy the land forfeited by unprofitable farmers." Already about 80% of farm receipts are earned by only 20% of the farms. Not only can larger farms afford more expensive equipment, they can use it effectively to plant and harvest substantial acreage within the growing season.

Over the past decade, manufacturers have offered machines of ever-increasing horsepower as tools for improving farm productivity. Now, the push is for more technological content, rather than brute force. For instance, a radar ground-speed sensor available on large Case tractors enables farmers to read the true tractor speed, and thus more accurately apply fertilizers or pesticides.

"Prospects for farm equipment really rest on farm income. If their income continues to decline, farmers will just fix the equipment they have."

Edward F. Wheeler
Senior Analyst
E. F. Hutton

This conservation of chemicals translates into big savings, says Gottman. A computerized hitch control on Massey-Ferguson tractors automatically adjusts plow height to compensate for changing soil conditions. This reduces fuel consumption by allowing the tractor engine to operate at a steady speed.

Similar replacement of other mechanical systems by computer control will greatly simplify tractor design and could reduce manufacturing costs, says Louis C. Harms, manager of original equipment manufacturing applications at United Technologies' Automotive Components Division (Springfield, Mass.). "Wires for electronic control are much more easily routed than mechanical linkages and are more easily sealed in air-conditioned and soundproofed tractor and combine cabs," he adds.

Whatever the future of high tech tractors, Deere's Saylor believes farmers don't have much choice. "If they're not on the forefront of technology, if they're not highly productive, in this sort of environment they get left behind."

—Jeffrey Zygmont

should be competitive with hand shearing, says Key.

Computers in the field. Many costly, time-consuming crop operations can also be aided through prescription farming. Researchers are thus investigating the use of robots, machine vision, and other advanced techniques that not only free the farmer for other tasks, but may also perform the operations more economically and in some cases more efficiently.

Conventional robotic devices for agriculture have so far been confined largely to the laboratory. One reason is the difficulty of designing robots for the hostile farm environment: Machinery that works well in the controlled conditions of a factory could easily fail when exposed to heat, dust, moisture, chemicals, and vibration.

Engineers at Louisiana State University (Baton Rouge) have had some success in developing a robot arm for transplanting seedlings, a repetitive task for which trained laborers are not always available. An automated transplanter for pepper plants was created by Heon Hwang and Fred Sistler of LSU's agricultural engineering department by combining a commercially available planter with a Rhino XR series Mark II robot arm and an Apple IIe microcomputer. A planter is a small wheeled cart, equipped with a simple arm, for depositing seedlings in the soil and covering their roots. It is normally controlled by an operator who must lift each seedling out of a tray and into a carousel that guides it into the planting mechanism. LSU's humanoid robot arm was adapted to eliminate the handling of each seedling.

In the initial tests, the robotized planter was able to transplant six seedlings per minute, with slight resets of the arm required after every tray of seedlings. This is substantially slower than present methods: Human operators can handle some 30 plants per minute, even using the planter without its conventional arm. Nevertheless, Hwang and Sistler concluded that the substitution of a specially designed manipulator for the humanoid arm would make the robotized planter relatively inexpensive to operate.

Another machine that's being updated is the tractor. Engineers at Texas A&M University (College Station) are developing an energy-sensing tractor that can talk to its driver. The tractor has already spent more than 18 months on working farms, says associate professor Stephen Searcy of the agricultural engineering department. The project is being supported by Deere & Co., the farm implements producer based in Moline, Ill.

Top: A mechanical transplanter lets growers transfer 648 seedlings to a flat in less than a minute. Bottom: Sunkist uses an x-ray scanning system to count oranges, sort them by size, and check them for disease or injury.

"Many farmers often run their tractors at low energy efficiencies," says Searcy. "We designed an on-board computer that monitors fuel consumption, the load on the engine, and drive wheel slippage. When these factors combine to reach a certain point, the computer tells the driver to 'shift up and throttle back,' and specifies the gear and engine speed for optimum energy efficiency." The Texas group has developed both a visual display and a limited-vocabulary speech board for the tractor.

Searcy concedes that an articulate tractor might be too gimmicky for many farmers. "It's sort of like the talking Coke machine," he says. "Most of us are pretty quick to figure out how to drop the coins in the slot. A more practical configuration might be to provide an audible alarm that tells the driver to look at a visual display." He adds that the concept could easily be extended to provide other information—a warning about a clogged seed tube on a towed planter, for example.

Automated herbicide sprayers are likely to be yet another important feature of prescription farming. These systems will apply expensive weed killers only where they are needed, thus reducing costs and minimizing environmental hazards. A machine vision system that can identify weeds by the shape

and orientation of their leaves is being developed by botanists Daniel Guyer, Gaines Miles, and Marvin Schreiber at Purdue University (West Lafayette, Ind.). In the near-infrared portion of the spectrum, leaves reflect 20% more energy than soil does, allowing solid-state cameras to distinguish the plants from the background.

The next step is more complex: using vision systems to identify species, so that the pesticide is directed to the weeds, not the crops. Measures studied by the Purdue researchers include analysis of a leaf's complexity (the ratio of its perimeter to its area), its elongation and thickness, and the plant's moment of inertia (a measure of the size of the leaves)—all characteristics that can be calculated by machine images made from above a plant. The error rate in one recent study of the system was only 9%, indicating that these features are sufficient for identifying weeds, the researchers reported.

Conventional pesticide delivery vehicles can be set to produce a constant spray of chemicals, but changes in the vehicle's speed (caused by slippage, for example, or changes in the ground slope) can seriously affect the amount of chemical delivered. When the vehicle slows down, even momentarily, the sprayers deliver too much pesticide.

Researchers at DICKEY-john (Auburn, Ill.) are trying to remedy that problem with an electronic system that senses ground speed and adjusts spray delivery accordingly. Doppler radar is used to determine the vehicle's speed, a valve controls the speed of the pump supplying the sprayer, and a sensor monitors the application rate. The problem becomes much more complex on vehicles with multiple dispensers, says DICKEY-john marketing specialist Thomas F. Ksiazek.

Such systems are currently being built, and while they provide much better control of spray application, they do not take into account variations from one part of a field to another. "What is lacking is the applied technology that will build the database for each individual field," says Ksiazek. "But it is not unreasonable to speculate about on-board computers that will store a field soil-type map, maps of localized weed or insect infections, and a map of soil fertility levels."

Automated harvesting. Harvesting remains one of the industry's most labor-intensive processes, and is thus ripe for technological innovation. One of the constraints is that machines must be at least as "skilled" as human workers to avoid excessive damage to fruits and vegetables between harvesting and packaging.

In East Lansing, Mich., ARS researchers have been experimenting with sonar systems that help keep a tractor on course as it moves between closely spaced trees in an orchard. "We know we can do it with present technology at a reasonable cost," says Galen Brown, director of the research team. He emphasizes that the tractor is not intended to replace the operator, but to relieve him of some of the tedium and visual strain of keeping the tractor traveling along a narrow path. "It's at least as tiring as driving a car down a narrow road for several hours," says Brown. "This will take much of the tension out of the job." The issues still to be dealt with are safety—preventing a malfunctioning vehicle from plowing into the farmer's living room, for example—and reliability. Brown estimates that it will take five or ten years to find solutions to those problems.

"Smart" farm equipment may one day take over such chores as killing weeds and harvesting and inspecting crops.

Brown is also investigating new technology for tree shakers. Such machines, which grab trees by the trunk, are now used to harvest a variety of fruits, including cherries in Michigan. Cherry trees are suitable for machine harvesting because they have tough bark and thus are not damaged by shakers.

Citrus trees, however, are more delicate. "We're using some advanced technologies to measure certain physical properties of the bark and cambium layer of the tree to assess the physical properties," says Brown. One example is a miniature pressure transducer that measures the stresses on the tree bark when shaking machines are turned on and off, in order to adjust the shaker accordingly. Damage to citrus trees can also be minimized by redesigning the trunk-grabbing clamps, or simply by equipping them with plastic or rubber grippers.

An automated lettuce-harvesting machine has been developed at the University of California at Davis. The harvester uses a radioactive beam to determine the maturity of lettuce. Low-level gamma rays emitted by a small sample of the radioisotope americium-241 are directed across a row of lettuce plants. The heads of lettuce scatter the radiation and reduce the amount that reaches a detector at which the beam is aimed. "This amount," says Roger Garrett, one of the developers, "is a measure of the size and density of the head, which turns out to be a good indicator of the maturity."

The device proved to be more accurate than an experienced field worker in determining maturity. The machine would probably sell for about $100,000, says Garrett, but could examine and harvest as many as two heads a second. One problem: That's faster than the lettuce can be boxed. As a result, the harvesting system will probably require changing the 24-head carton to a larger package.

Garrett acknowledges the obstacles that still stand in the way of his harvester (and a similar one developed by the USDA in Salinas, Cal.). "Most growers aren't prepared to make that investment yet," he says. "If they reach the point at which labor is scarce, or if they can't compete with other sources, they'll take another look at the economic potential." Still, he is optimistic about the invention's commercial prospects, especially among California lettuce growers; the state's long growing season could justify the large capital expenditures required by automation. (Weighing against that argument, however, is California's dependable supply of skilled labor.)

Faster food processing. Food processing is yet another candidate for agricultural automation. Sunkist Growers (Ontario, Cal.) has developed an automated inspection, grading, and packaging system with features not available in commercial color sorters used by citrus shippers, says Maurice Johnson, the company's director of research and development.

First, the fruit is passed on a conveyor through a low-level x-ray scanner that detects variations in density from injury, disease, or other damage. The system also sizes by volume, rather than weight, using a pair of cameras. A computer calculates each fruit's volume and records the number of fruit of each size as well as the total number processed.

Octek (Burlington, Mass.) is studying the feasibility of sorting chicken parts using digitally processed images. A similar system, says Marie Harris, the company's marketing communications manager, is being developed to grade beef. It differentiates between fat and lean meat by a technique called thresh-

PHIL MATT

Cornell's Gerald Rehkugler with his digital imager for spotting bruised apples. Infrared light is bounced off the fruit; damage is signaled by variations in reflectance.

olding. Shipboard sorting of fish species for immediate processing is another application now being tested, says Harris.

Infrared digital imaging is being adapted for detecting bruises in apples by Russell Taylor and Gerald Rehkugler of Cornell University (Ithaca, N.Y.). The quality of apples is now determined by random sampling; automated inspection systems could examine every apple, then separate the bruised pieces from the undamaged fruit.

In the Cornell system, infrared light is bounced off the apples to test their reflectance, which varies where bruises appear. The engineers are now developing an industrial handling system that will present 30 apples a minute to a digital camera. The examination method has commercial potential, say its developers, but in some cases half of the bruise area on sample apples was missed. At the moment, they say, "it is not clear if the accuracy would be sufficient to warrant full-scale development."

A threat to workers? An overriding question with all of these new technologies is what their effect will be on jobs. In 1979, California Rural Legal Assistance (a farm workers' rights organization) filed suit against the University of California, arguing that research that could displace workers should not be done at publicly funded institutions. After several delays, the trial was set to resume late this year.

It seems clear that in the short run, mechanization often reduces the number of workers in any industry, including agriculture. What is not so clear is whether such jobs are permanently lost or are simply shifted to other areas. At least one study suggests the latter. Since 1960, fewer agricultural jobs have been lost to mechanization than have been created by the resulting expansion, according to economics professors Philip L. Martin and Alan L. Olmstead at the University of California at Davis. They estimate that 192,000 farm workers were employed in California in 1960; despite increasing mechanization, the number reached 224,000 in 1980.

And, they say, science was to thank for many of these new jobs. They cite successes in breeding strawberries, for example, that increased yields and lengthened the season from two months to six.

The California suit provides another example of the double-edged nature of mechanization. While the action cites the tomato harvester for eliminating workers, economist Patrick Madden at Pennsylvania State University's Institute for Policy Research argues that the harvester actually saved jobs by revitalizing California's tomato industry. Without the harvester, he says, the state's tomatoes would have been unable to compete with imports.

Whatever the outcome of the suit, many researchers agree with the University of California's Garrett that "automation must and will come. If we proceed with understanding of and sensitivity to the concerns, we can help define ways to minimize the adverse social impacts and, hence, promote acceptance of automation." □

Paul Raeburn, a New York–based science reporter, holds a degree in physics from MIT.

For further information see **RESOURCES**, *p. 69.*

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A growing number of industries are discovering the virtues of a sophisticated new cutting tool: water. Materials as diverse as brake linings, printed circuit boards, and advanced aerospace composites, not to mention more mundane items like cardboard, baby diapers, and candy bars, are being quickly and cleanly cut by needle-thin jets of water forced out of sapphire nozzles at velocities approaching three times the speed of sound. And while hard, dense materials like glass and metal were once excluded from the list of candidates for water-jet cutting, that threshold has been crossed by mixing fine grains of silica or other abrasives with water.

Virtually all of General Motors' auto carpets are being cut with water jets, according to Ron Adams, marketing and sales manager for McCartney Manufacturing (Baxter Springs, Kans.), which introduced the first water-jet system in 1971. Meanwhile, Rockwell International in Columbus, Ohio, is using the method to cut certain parts of its B1-B bomber. Unlike high-speed mechanical cutting, the method does not produce jagged and burned edges; as a result, the operation has been dramatically speeded up. "They claim they can now cut 12 parts in the time it once took to polish one," says Adams.

Major markets for the systems now include electronics (cutting printed circuit boards, for example), aerospace, and auto production, where water jets team up with robots to cut floor mats, gas-tank shields, and fiberglass body parts. Food processing is a somewhat smaller market, but Adams expects it to grow rapidly during the next few years. "You can imagine what a hot, gummy slab of caramel does to a conventional blade," he says.

With price tags of up to half a million dollars, the systems don't come cheap; most shops are limited to one or two cutters (although some larger sites might run half a dozen or more robotized units). Approximately 600 systems are now in use worldwide, however, and sales are reportedly growing at 25% to 30% a year.

There are several advantages to cutting with water. One is that unlike mechanical saws, the method produces little or no debris. And while saws can cut only in straight lines, water jets can cut in all directions; indeed, cutting intricate shapes with a water jet is as easy as drawing with a pencil. And since water jets cut without generating heat, they leave metallurgical properties unaltered—a sharp contrast to the thermal effects induced in metals by plasmas, lasers, and acetylene torches.

The corrugated box industry was one of the first to use water as a cutting tool. Not only can linerboard be cut at higher speeds with water jets than with conventional slitting knives, but the near-dustless high-pressure jet means that downstream printing rolls don't need to be cleaned as often. Dustless cutting also became an irresistible lure for the asbestos and fiberglass industries, as well as in the manufacture of shoes and garments.

The heart of a water-jet system is a

by Ernest Raia

pair of pumps; one of them (a standard motor-driven hydraulic piston pump) drives the other (a reciprocating plunger-type pump called an intensifier). Hydraulic oil is delivered to a large piston in the intensifier, driving it back and forth in the cylinder. Connected to this large piston are two smaller piston plungers that pump the water through the system under high pressure. The output water pressure is greater than the input oil pressure by the ratio of the two piston areas, which generally is between 10:1 and 20:1. Thus, if the input oil pressure is 3000 psi, the output water pressure can range as high as 60,000 psi. The pressure of the water jet can be controlled by regulating the oil pressure.

Such high pressures led to a major problem in early water-jet systems—a rapid wearing of the piston seals, which resulted in a mean service life of only about 25 hours. Through improvements in seal materials and design, however, the service life of water-jet systems is now more than 500 hours, according to Jack Atkinson, product manager at Flow Systems (Kent, Wash.). Systems are reportedly under development at three other companies as well: Acme-Cleveland—which teams its robots with McCartney's water-jet unit—England's Jetlin, and Japan's Sugino.

A robot-controlled jet of water cuts a sheet of molded plastic to produce an interior truck-roof panel. Such highly customized water jet systems may cost up to $500,000.

Another key piece of equipment is the accumulator. Because water is compressible under high pressure, at 60,000 psi no water comes out of the pump during the first eighth of the piston stroke. The accumulator, which contains no moving parts and is simply a storage tank for compressed water, ensures that water flows continuously out of the system at uniform pressure and velocity when the piston reverses direction in the intensifier.

From the pumping unit the water is carried to the nozzle via commercial high-pressure tubing. The nozzle is usually fabricated from synthetic sapphire in which pinholes that are 0.003 to 0.012 inch in diameter have been drilled. These low-cost nozzles have a life expectancy of about 200 hours; when they fail, it is generally because of dirty water (including hard water containing mineral deposits). Nozzle life is easily extended simply by using filtered and softened water. Since water consumption is quite low—on the order of 1–2 gallons per minute in a typical system—the use of deionized water will not have any great impact on operating costs.

The last important element in a water-jet system is the catcher, which can be nothing more than a simple pipe. The catcher serves two functions, both related to worker protection: It acts as a safety guard and as a muffler. A jet of water traveling at 3000 feet per second and at 60,000 psi is as dangerous as a power saw; it's therefore desirable to keep the exposed water jet as short as possible. The catcher also muffles the loud pop of the water breaking into droplets after it passes through the material; that sound has been measured at 130 decibels.

Fortunately, the water jet's cutting ability is greatest near the nozzle. Air, it seems, will "dull" the jet more quickly than solid substances. While the jet can easily cut through 10 inches of fiberglass positioned within an inch or so from the nozzle, it fans out and loses all of its cutting ability after passing through 8 inches of air.

Water alone will cut most porous materials; but to cut metals, abrasives need to be mixed into the jet. In the abrasive water system developed by Flow, high-pressure water enters the center of a mixing chamber into which abrasive particles (typically garnet or silica) are fed from side ports. The water entrains the abrasives and accelerates them to high velocities. The mechanism by which the material is actually cut is altered by the addition of abrasives: Whereas plain water cuts by compressive shear, the abrasive slurry relies on erosive action. High-pressure abrasive slurries have cut through 14-inch concrete slabs at the rate of 1 inch per minute (ipm), through 3-inch tool steel at 1.5 ipm, and through 1-inch mild steel at 8 ipm. Titanium reportedly can be cut as easily as steel with abrasive slurries, and sandwiched honeycomb titanium—a material used in the aircraft industry—has been cut at rates of up to 30 ipm.

There are hundreds of other potential applications in the aerospace, glass, automotive, ceramics, and metalworking industries, from cutting heat-exchanger cores and ceramic catalytic converters to laminated glass, armor plate, and composite missile cases. Complete water-jet systems can cost from $50,000 to more than $500,000, depending on complexity and customization. □

Ernest Raia is a former senior editor of HIGH TECHNOLOGY.

THE BIRTH OF ELECTRONIC PHOTOGRAPHY

Video floppy disks challenge slides and prints

The use of film for making still images remains a bastion of photochemical technology in an increasingly electronic world. But if the Japanese have their way, conventional photographs may eventually be replaced by electronic images. Four companies in Japan are developing electronic cameras that record color stills in the form of analog video waveforms on miniature floppy disks.

Electronic cameras offer a number of advantages over their film counterparts, including speed, convenience, and ease of use. Currently, drawbacks include less than optimal picture quality and high equipment cost; however, once these problems are resolved, electronic cameras will likely spread from their initial industrial and commercial applications into home use.

The new disk format, known as video floppy disk, is smaller than both the conventional $5\frac{1}{4}$-inch floppy disk and the $3\frac{1}{2}$-inch mini-floppy used in the Apple Macintosh and other personal computers. Employing a high-density recording medium, the video floppy disk is encased in a hard protective sleeve 1.85 inches square and 0.025 inch deep, making it durable enough to send through the mail. The dimensions of the disk were established as an industry standard by the Electronic Still Camera Standardization Committee of the Electronics Industry Association of Japan. This standard also specifies a recording format of 50 tracks (images) per disk, with one video field recorded per track.

Conventional moving video images are recorded at 30 frames per second, with each frame consisting of two interlaced fields of odd and even scan lines (fields are recorded at a rate of 60 per second). Still video images must employ a different recording technique, however. If each frame consisted of odd and even fields recorded consecutively (as in normal video), any slight movement in the time interval between recording the two fields would result in a noticeable discontinuity, or "jitter," between the scan lines. (Some jitter occurs in conventional video, but it is not apparent when the images are constantly moving.) To solve this problem, electronic still cameras have been designed to record a single field of odd-numbered scan lines. This field information is then processed digitally in the camera to interpolate the missing even-numbered scan lines, generating the full-frame image.

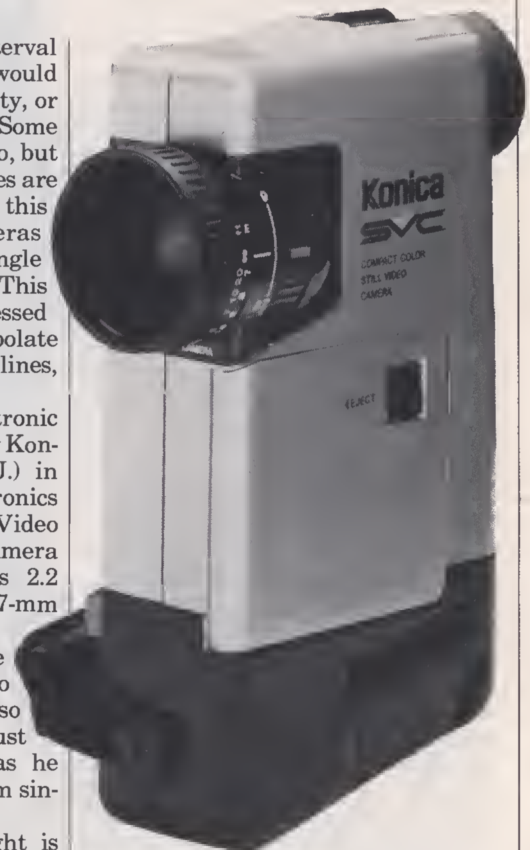
by Robert Rivlin

The latest prototype of an electronic still camera was demonstrated by Konica USA (Englewood Cliffs, N.J.) in June at the Consumer Electronics Show in Chicago. Called the Still Video System, it resembles a movie camera and is battery-powered, weighs 2.2 pounds, and comes with a 9–27-mm zoom lens. A beam-splitting arrangement allows some of the light entering the camera's lens to be seen through the viewfinder, so that the photographer can adjust the viewing angle and focus as he would with a conventional 35-mm single-lens reflex (SLR) camera.

The rest of the incoming light is diverted by the prism onto a solid-state imaging chip known as a charge-coupled device (CCD). This half-inch chip has on its surface 180,000 separate sensing elements, which generate electric charges in proportion to the intensity of light striking them. The charges are then read out to generate an electronic representation of the scene. When the camera's shutter release is pushed, the stream of video information flows to a magnetic recording head, which records it on the video floppy disk.

The Konica Still Video System takes pictures either one at a time or continuously, at a rate of eight images per second. This continuous mode of operation is like the motorized film-advance feature offered by many 35-mm SLRs, and permits taking rapid sequences of pictures—for example, during sports events. A liquid-crystal display provides such information as which track is being used (the shot number) and whether the camera is in single-shot or continuous mode.

Electronic stills clearly must be viewed differently from prints or



The prototype Konica still video camera, which weighs just over 2 pounds, works in either single-frame or continuous mode. It can record 50 frames on a 1.85-inch floppy disk.

slides. In the Konica system, the video floppy disk is ejected from the camera and inserted into a still player looking somewhat like a videocassette recorder (VCR). The viewer can move rapidly forward or backward through the stills, call up a particular still by number, or set the system to sequence automatically through the stills at a speed matching that at which they were shot, thereby simulating animation. The user also has the option of displaying the date and time at which the still was made.

For users who insist on having a hard-copy version, the Konica system will include a printer that produces 5×7-inch printouts on photographic paper. In addition to electronic stills stored on a video floppy disk, the printer will be able to record images from any standard video source, including a TV set or a VCR. Konica plans to mar-

ket its video printer in about a year.

Konica is not alone in seeing the potential of electronic stills for the consumer photo market. A viewing system made by Eastman Kodak (Rochester, N.Y.) will soon begin consumer testing. With this system, users will send rolls of film to processing labs for conversion to floppy disk. The system's player/recorder not only displays floppy disk photos but also makes video stills of TV or computer images. The other major component, a color video imager that makes hard copies of video photos and other on-screen images, will become commercially available this winter for about $700.

Fuji has also developed a playback system, which will reach the Japanese market as soon as film-to-disk transfer machines have been installed in the firm's processing labs. Fuji may decide to design its own electronic still camera as well.

Sony (Park Ridge, N.J.), the first to develop an electronic still camera, has decided not to enter the market until the technology is more advanced and its commercial prospects are more certain. Sony introduced a prototype of its Mavica electronic camera in Japan in August 1981, and showed it in the U.S. in March 1982. The Mavica is shaped like a standard 35-mm SLR, weighs 1.75 pounds, and uses three rechargeable nickel-cadmium batteries that provide enough power for 200 images. The camera can be fitted with two fixed-focal-length lenses (22-mm wide-angle and 50-mm standard) and a 16–64-mm zoom lens. It also features shutter speeds ranging from a sixtieth to a two-thousandth of a second, an automatic through-the-lens light meter, a self-timer that allows the photographer to get into the picture, and variable-speed automatic recording.

Sony's initial version of the Mavica has a CCD imaging chip with 280,000 sensing elements, giving it a resolution almost as good as a broadcast-quality TV camera. Because Sony sees the principal advantage of the Mavica system as providing "instant viewing" of stills, it has developed a still player that offers forward and backward cueing and remote control. (A future development will allow users to stack video floppy disks in a carrier, the same way slides are stacked today.) A color video printer rounds out the system.

Although Sony announced the Mavica with great fanfare in late 1983, the company subsequently decided that the product needed further development—mainly to improve the resolution of the CCD imaging chip—before it could be marketed. Sony may also decide to let companies such as Konica invest the large sums of money required to develop the consumer market, particularly since Konica has the advantage of already being a still-camera manufacturer while Sony would be entering the field from outside.

Another potential entrant in the electronic-camera market is Canon USA (Lake Success, N.Y.), a leading manufacturer of 35-mm SLRs. At last year's Olympics in Los Angeles, Canon tested a prototype electronic camera with shutter speeds of up to a thousandth of a second, an electronic flash, and standard 35-mm SLR bayonet-mount lenses. This camera enabled Japanese press photographers to transmit still photos to a Tokyo newspaper within minutes after they were shot. A disk player was used to read the video-still information into a modem, converting the analog picture information into digital data that were sent over a phone line from Los Angeles to Tokyo. At the destination, the digital data were converted back into the analog video signal. The transmission time was eight minutes for good TV-quality black-and-white images, and slightly longer for color. Thus a memorable image of Carl Lewis winning the 100-meter dash appeared on the front page of a Tokyo newspaper shortly after the win took place several thousand miles away. Because of the obvious appeal of electronic still cameras to wire-service photographers, Canon may market its camera in the next few years as part of its professional and industrial products line.

Hitachi (Compton, Cal.) has also made a prototype electronic camera, which was first shown at the 1984 Consumer Electronics Show. Instead of a CCD imaging chip, the Hitachi system uses a metal oxide semiconductor (MOS) chip. The camera also features a beam-splitting system and a maximum shutter speed of a five-hundredth of a second. Although Hitachi considers the camera too expensive and unwieldy for the consumer market, it may be added to the company's industrial products line.

Electronic cameras offer some important advantages: They are virtually foolproof to use, provide almost instant viewing of images, require no messy developing chemicals, and permit disks to be erased and reused if desired. Showing electronic stills is more convenient than setting up a slide projector and screen, and the images can be enhanced electronically to make up for poor color or lighting. And while color prints tend to fade and change color over time, magnetic media are stable indefinitely if stored correctly (although they may be less durable with frequent use).

Despite these advantages, however, the sharpness of electronic stills will have to be improved significantly if they are to appeal to the consumer market. High resolution is less critical for wire-service or newspaper photos, but the sharpness of electronic stills viewed on an ordinary TV set is still inferior to that of conventional slides and prints.

To address this problem, Fuji, Sony, and other companies are developing high-density CCD chips. The companies have a short-term goal of 400,000 sensing elements and a medium-term goal of 1.6 million. If such chips can be made cheaply enough, electronic cameras should be able to generate stills with a resolution comparable to that of 35-mm prints.

Still, the anticipated high cost of electronic cameras will create another obstacle to their success in the consumer market. Once video floppy disks are mass-produced, the price per disk may be comparable to that of a roll of film. But the retail cost of the cameras themselves will probably be quite high compared with standard 35-mm SLRs. The reason is that while electronic cameras will need the same optics and metering systems as conventional SLRs, they will replace the relatively cheap mirror and shutter mechanism with a more sophisticated and costly solid-state imaging chip and magnetic recording head. Consumers will also have to pay the added cost of a disk player to view the images.

Because of these cost constraints, electronic-camera technology will probably find its initial applications in industrial and commercial markets. It will then spread to a few pioneering home enthusiasts, much like the first generation of home video cameras, and will coexist with photochemical photography for at least the first 5–10 years. As the public grows more used to electronic stills, however, conventional slides and prints may eventually become antiques. □

Robert Rivlin, who lives in New York City, is editor and co-publisher of Video Graphics & Effects *magazine and a freelance technology writer.*

SCRAMJETS AIM FOR MACH 25

Proposed engines could lead to ultrafast planes, lightweight launch vehicles

Aircraft and missiles capable of cruising at hypersonic speeds at very high altitudes could be the payoff of a novel jet propulsion scheme being studied by NASA. Wind-tunnel tests of engine models indicate that the supersonic-combustion ramjet (scramjet) could reach speeds as high as Mach 12—twice as fast as the highest speed attainable with conventional air-breathing propulsion technology. Industry studies of the scramjet sponsored by the Defense Advanced Research Projects Agency (DARPA) suggest that its potential maximum speed may even be higher—up to Mach 25, which would be sufficient to propel a vehicle into orbit.

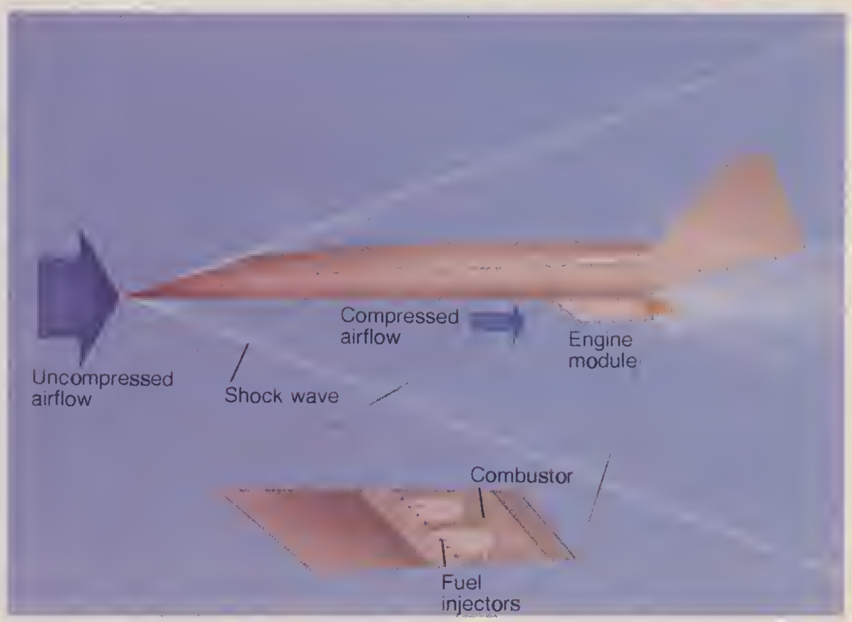
Rocket engines used to power missiles and space launchers have routinely achieved such speeds for decades. However, rocket engines require a supply of oxidizer in order to burn fuel. In contrast, the scramjet breathes its oxidizer—air—from the atmosphere, thereby eliminating the weight and cost of on-board oxidizer. As a result, the scramjet could substantially reduce the cost of developing and operating high-speed aircraft—from long-range cruise missiles to transatmospheric vehicles.

The scramjet is a variant of the ramjet. Such an engine creates thrust by breathing air through an inlet, compressing it, mixing it with fuel, and then burning the mixture to create a mass of hot gases that are then exhausted through a nozzle. The ramjet dispenses with the turbine-powered compressor employed in most conventional jet engines to compress the airflow. Instead, it relies on the forward motion of the aircraft to ram air into its inlet. At supersonic speeds, this ram action compresses the airflow sufficiently to achieve useful thrust.

As air rams into a turbojet engine, it encounters drag and consequently heats up. At speeds of about Mach 3, the combined effects of aerodynamic heating and combustion raise the internal temperature of the gases that turn the turbine to about 2300° F. This is the maximum temperature sustainable by turbines employing state-of-the-art materials and cooling techniques. Thus Mach 3 is the practical speed limit for conventional turbojet engines. But because it eliminates the compressor and hence the turbine, the ramjet can go beyond this limit.

Conventional jet engines designed to operate at supersonic speeds attempt to minimize the ram-down (air-slowing) effect—and the resultant aerodynamic heating—by inserting cone-shaped structures in the inlet, with their tips protruding forward of the lip. A cone-shaped forebody, in effect, gives the engine a swept inlet, and hence reduces drag at supersonic speeds, just as a swept wing does. But even with a forebody, the airflow in a conventional ramjet slows to subsonic speeds within the engine. When an aircraft reaches Mach 6, the ram-down effect heats the airflow above 2700° F. At these temperatures, fuels cannot deliver useful energy when they burn; instead, the fuel molecules form a variety of partially burned fragments, losing energy in the exhaust.

Minimizing aerodynamic heating by reducing the ram-down effect requires that the airflow within the engine maintain supersonic speeds. A scramjet is unique in its ability to do this, but it requires a long forebody. Thus, to avoid increasing the engine size, the NASA concept calls for integrating the scramjet's forebody with the airframe. The engine inlets would be slung beneath the fuselage so that the aircraft's needle-like nose would serve as the engine's forebody. The net result would be to reduce the ram-down effect and hence to allow air to flow through the scramjet engine at higher velocities—above Mach 1, instead of at subsonic speeds as in a conventional ramjet or turbojet. The increased airflow velocity reduces aerodynamic heating, thereby allowing greater aircraft speeds.



MARK E. ALSOP

NASA's supersonic-combustion ramjet would eliminate the nozzle and forebody used in conventional ramjets. Instead, the aircraft fuselage would be shaped to allow air to flow at supersonic speeds through the engine. Because conventional hydrocarbon fuels would take too long to mix and burn in the supersonic airflow, the NASA design would use hydrogen gas as its fuel.

by T. A. Heppenheimer

In the NASA integrated scramjet concept, the aft portion of the aircraft underbody would be shaped to serve as the upper half of the engine's nozzle. This would not only save weight by eliminating a component but would also reduce drag. At high speeds, an airframe experiences a pressure difference between its forward and aft surfaces that effectively creates drag. In an integrated design, the engine exhaust acting on the aft underbody would equalize the pressure.

But allowing supersonic flow inside the engine poses a significant problem: how to sustain combustion. The airflow moves so quickly through the engine that there is very little time for fuel to mix with the air and burn. At high speeds, such as Mach 7, a fuel particle stays in the combustor for less than a millisecond; if the fuel does not burn, the engine will flame out.

To reduce combustion time, the NASA engine would use hydrogen, which burns very rapidly compared with the hydrocarbon fuels employed in conventional jets. The hydrogen would be stored in liquid form to minimize fuel tank size, but would be injected in gaseous form to speed combustion. To shorten mixing time, the engine would employ a novel form of fuel injection. Conventional ramjets inject fuel from the engine walls, which remain relatively cool. In contrast, the NASA engine would mount fuel injectors on struts spanning the middle of the engine and hence the airflow. Because the struts must be able to withstand the intense heat in the center of the engine, they would be made of high-temperature metals such as nickel and would be cooled by circulation of the liquid hydrogen before it is injected into the combustion zone.

The scramjet sounds impressive in theory, but will it work? To answer this question, researchers at NASA's Langley Research Center (Hampton, Va.) have been constructing and testing scale models of scramjet engines since 1978, working closely with General Applied Science Labs of Westbury, N.Y. Similarly, in recent years DARPA has been funding scramjet research managed by the Aeronautical Systems Division at Wright-Patterson Air Force Base in Ohio. Under the DARPA program, major engine and airframe makers (their identities are classified) have been using advanced computational methods to study the integration of engines and airframes, modeling the airflows with particularly high accuracy.

Preliminary results from the NASA and DARPA studies have been encouraging. In over a thousand test runs, the NASA engines have demonstrated sufficient thrust to accelerate a large aircraft to speeds as high as Mach 7—the maximum speed of the NASA wind tunnel. Extrapolating from these results, Ernest Mackley, director of NASA's hypersonic engine research program, believes that the design concept should be feasible up to Mach 12. The DARPA studies have concluded that by using inlets and nozzles with variable geometry (the ability to change shape with increasing speed), scramjets could operate at up to Mach 25, which is orbital velocity.

These studies have convinced influential observers that scramjets would indeed work. "Hybrid air-breathing propulsion systems [such as the scramjet] are now viewed as feasible over the long term," wrote presidential science adviser George A. Keyworth II in a March 1985 report entitled "National Aeronautical R&D Goals." Robert S. Cooper, who resigned as DARPA director in July to start a private consulting business, is similarly impressed. As head of DARPA he said, "We are ready to make a major push in this area."

Both Keyworth and Cooper envision the use of air-breathing engines as a replacement for rockets in tomorrow's launch vehicles. When the Space Shuttle is on the launch pad, it carries over 650 tons of liquid oxygen but no more than 32 tons of payload. Air-breathing engines in a craft of similar size would permit a vast increase in payload. Alternately, such a vehicle could be much smaller and lighter than the shuttle, while carrying the same payload. An air-breathing launch vehicle might use ground facilities like those of an airport or Air Force base, rather than those of Cape Canaveral. It could well be less costly than a rocket craft and pose less development risk.

The emerging Air Force interest in a transatmospheric vehicle (TAV) has brought these issues into focus. The TAV is supposed to fly to orbit on very short notice, making two flights a day, while operating from conventional runways. This would give it the advantage of surprise and quick reaction in reconnaissance. By flying on unpredicted courses, it could observe secret Soviet facilities before they could be hidden, or it could reach orbit quickly enough to shoot down an antisatellite system that was maneuvering to shoot down a U.S. spacecraft. If an important satellite were lost, the TAV could quickly launch a replacement.

The scramjet could offer a cheaper alternative to the rocket engines currently envisioned for the TAV. But there are some flies in the ointment. One is that a scramjet-powered TAV would need some form of auxiliary propulsion, such as a conventional turbojet, to reach the supersonic speeds required for effective ram action. This requirement would somewhat offset the cost and weight savings.

Perhaps a more serious obstacle is the lack of hypersonic test facilities, which has prevented verifying scramjet performance over the full range of altitudes and speeds proposed for the TAV. NASA's Langley Research Center is modifying an existing Mach 7 wind tunnel, with an 8-foot-diameter test section, to permit testing of larger scramjet models. But it won't be completed until after 1988, according to current schedules, and it won't allow the necessary testing at higher simulated speeds and altitudes.

Moreover, current budgets will not allow for constructing the needed facilities. NASA's 1985 budget for scramjet research is only \$2.7 million, and the DARPA program is funded at a level of a few million dollars per year. This situation led Cooper to conclude that "there is an opportunity to up the ante by a factor of 10, or even 20 or 30, over what is being spent now, and to make this technology really move rapidly."

In fact, DARPA is already moving to step up scramjet research. In congressional testimony in July, Charles Buffalano, acting DARPA director, announced the agency's intention to expand its hypersonic engine research program. Under the program, the agency hopes to build two scramjet engine modules and test them at speeds of up to Mach 8 or 10 in wind tunnels that are to be built for this purpose.

Buffalano estimates that the program would require two to three years and several hundred million dollars to achieve its objectives. Its cost would be too great for DARPA to bear alone, so the agency is seeking support from NASA, the Air Force, and the Navy.

T. A. Heppenheimer, a writer in Fountain Valley, Cal., has a PhD in aerospace engineering.

VIDEOTEX ENTERS CORPORATE CHANNELS

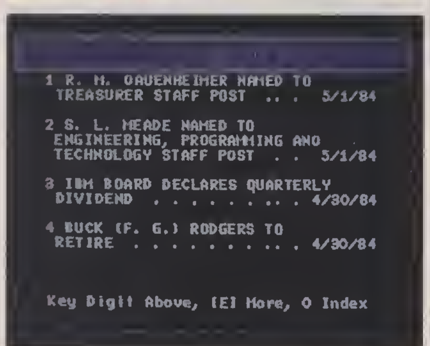
Disappointed by residential sales, vendors are gearing systems to companies

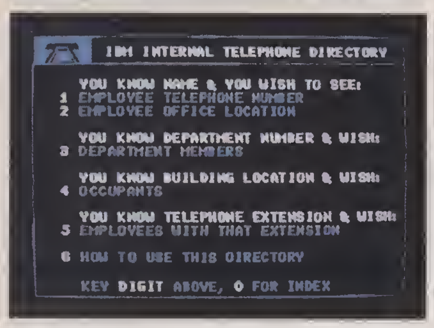
Videotex, long heralded as an up-and-coming information-distribution technology for the residential marketplace, still has a long way to go. Applications such as electronic banking, news reports, and remote shopping hold potential, but the home market is warming up to them much more slowly than anticipated. As a result, many videotex vendors are adapting their systems to industrial applications, including the intracompany delivery of personnel and financial data, employee access to outside databases, and the transmission of product and service information to customers. Offering these services for viewing on popular personal computers is helping to boost the market.

In offices, videotex can present computer-based information in easily accessible and colorful ways. Although the technology is unlikely to replace conventional database management systems, commonly requested information—such as personnel benefits, telephone numbers, and specifics from training courses—could be more attractive to nontechnical employees if converted to videotex format. Compared with the run-on text screens that a database management system would produce, videotex pages are easier to search through and comprehend; the format typically consists of introductory pages that list menus of options, and information pages that can contain both text and graphics. In addition, corporations could place catalog-type product information in a videotex format that customers could access using home terminals and telecommunications links.

At its heart, videotex is simply a means of digitally encoding text and graphics, combined with a means of transmitting the encoded information to users. The service supplier creates discrete pages, or frames, of information for display on specially configured TV sets or computer terminals. In current parlance, videotex (sometimes called viewdata) implies some degree of interactivity—it lets the user exchange information with the service provider. Transmission occurs via cable TV or telephone networks, which can support two-way applications such as financial transactions and electronic messaging.

by H. Paris Burstyn





Like several other vendors, IBM promotes the corporate applications of the page-oriented videotex technology. These include graphic presentations of information such as hotel locations in different cities (top), on-line corporate newsletters (middle), and easy-to-use telephone directories (bottom).

A sister technology, teletext (or broadcast videotex), differs in that it is a one-way service that supports noninteractive applications such as stock listings or weather and news reports. This service typically broadcasts data over the empty bandwidth created by the vertical blanking intervals that exist between the frames of TV pictures.

Vendors selling business videotex systems hope to capitalize on both the successes and the mistakes of the residential market pioneers. Probably the most important videotex achievement so far has been the gradual appearance of standards for encoding the information to be presented. In the U.S. and Canada, a standard known as NAPLPS (North American Presentation Level Protocol Syntax) has begun to take hold. NAPLPS gained popularity largely through the efforts of its creator, AT&T, which based the standard on a proven Canadian protocol called Telidon.

Like most videotex standards—there are several worldwide—NAPLPS supports various alphanumeric character sets and provides control functions to specify color, character height, and character width. Unlike some earlier standards, however, NAPLPS provides coding for "alphageometric" graphics. This code describes graphics "primitives" such as lines, arcs, and polygons, and produces much sharper images than "alphamosaic" protocols, which can create only blocky, stair-step pictures.

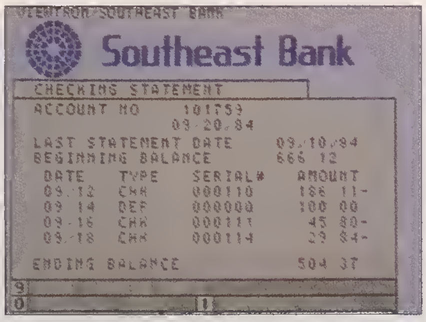
U.S. vendors assessing the risks of the business videotex market have closely followed the saga of Viewdata Corp. of America, a subsidiary of Knight-Ridder. Viewdata has invested $42 million in various residential videotex projects, marketed under the Viewtron label. Its flagship project, based in the Miami area, has had difficulty attracting subscribers. Offering services such as home banking, the Miami Viewtron project lost approximately $17 million during 1984, after fewer than 3000 of the expected 5000

subscribers signed up for the service. In October of that year, Viewdata laid off 20% of its 210 employees, because of the low subscription rates. In a different region, Affiliated Publications, the parent company of the *Boston Globe,* decided last June to delay a planned offering of the Viewtron service in New England, citing a variety of reasons, including "an uncertain market and unresolved questions with Knight-Ridder."

A major barrier faced by Viewdata and most other residential service vendors is the need for home users to have display devices that can accept the coded videotex information. In Miami, early Viewtron subscribers had to buy a $600–$900 videotex terminal, in addition to paying a $12-per-month subscription fee. Later, the monthly fee was increased to $39.95, which included lease of the terminal. Only recently has Viewdata moved to take advantage of the growing base of personal computers in homes. In October, it launched a service that permits subscribers to access the system using Commodore, Apple II, and IBM PC (and compatible) computers that run special videotex software—a move that should permit Viewdata to offer much more attractive rates.

But while a growing number of homes have personal computers, the installed base of PCs in corporations is far larger. This is one of the major reasons why videotex vendors have been drawn to the business market. As with the Viewtron option, personal computers in corporations can be modified to accept videotex information, obviating the need for specialized terminals. AT&T, IBM, and other vendors sell add-in boards that allow microcomputers such as IBM PCs and compatibles to interpret NAPLPS code. But modifying personal computers to accept NAPLPS code solves only half of the problem; corporations must also wear the hat of information providers. That is, companies must convert existing computer-based information into videotex page formats or build videotex frames from scratch.

IBM recently introduced two products designed to address this need. One, the PC/Videotex Graphic Artist Facility, lets corporate users create



Following early setbacks, consumer videotex services such as Viewdata's Viewtron home-banking system are starting to achieve increased market penetration.

videotex frames on PCs and then transfer them to a host computer. The second product, Videotex/370, permits an IBM 370 mainframe to store and distribute videotex frames while it continues to perform other data-processing applications. Together, the products give IBM customers the capability of developing in-house videotex systems, complete with graphics, from their internal databases.

To encourage users to try videotex, IBM is also offering a service over its IBM/Information Network through which customers can begin developing their videotex database on a timesharing basis. If they like the results, they can then opt for their own software and bring the program in-house.

IBM is not alone in addressing the corporate marketplace. After an early focus on residential users, AT&T has also moved strongly into business systems. Last summer, the communications giant introduced two workstations designed to create videotex frames. The Frame Creation System 350, for example, incorporates both a graphics tablet and a video camera as graphics-input devices. Scenes taken with the video camera are digitized for computer storage and video display, and can be combined with computer-generated text and graphics.

Ironically, the AT&T 350's ability to digitize video information raises an issue about the relevance of the AT&T-developed NAPLPS videotex. NAPLPS cannot deal with the lengthy, uncoded stream of bits that results when a video image is digitized. In fact, NAPLPS specifically incorporated alphageometric graphics primitives not only to improve upon the alphamosaic block images, but also to conserve bandwidth over the transmission medium. A few lines of computer code substitute for the bit stream that would otherwise compose a picture; at the receiving end, the terminal decodes the NAPLPS-encoded information and then displays the image.

This data-compression advantage of NAPLPS encoding will become increasingly questionable as fiber optic capacity and intelligent-network switching become commonplace. Consultants at Arthur D. Little (Cambridge, Mass.) predict that transmission costs will fall more rapidly than processing costs, making it less expensive within several years to send the unencoded bitstream over the network than to decode the NAPLPS at the terminal.

Behind these transmission economies are the large-scale investments in fiber optic cable currently being made by virtually all the long-distance telecommunications carriers and regional telephone companies. Over the next two years, for example, United Telecom of Kansas City plans to spend $2 billion on fiber capacity; and AT&T plans to link 37 cities with almost 10,000 miles of fiber cable by 1990. AT&T's investment in its network alone will run more than $2 billion each year, excluding buildings and outside equipment.

While excess capacity may partially undermine the bandwidth-conservation features of videotex codes, it should also boost the overall market for videotex applications. As the common carriers add to their capacity, they will look for services to offer their customers in order to fill the networks. Many of these services are likely to consist of computer-based information that the menus and colorful graphics of videotex may help make more attractive to subscribers. Reflecting the lessons learned from previous videotex experiments, most of the early network services will likely be aimed at business clients. □

H. Paris Burstyn is an analyst with the World Telecommunications Information Program at Arthur D. Little (Cambridge, Mass.).

PERSPECTIVES

Guiding high tech firms into China

Shaking off decades of Maoist isolation, China is seeking foreign investment and technology. Western businesses, meanwhile, are eager to tap the potentially huge market represented by the country's 1 billion people. But many cultural and language barriers still stand in the way. To help break through them, the Georgia Institute of Technology has formed a partnership with the Chinese that is expected to generate billions of dollars worth of business for small to medium-size companies throughout the U.S.

The partnership, called China/Tech, calls for Georgia Tech to serve in an advisory capacity in joint business and research ventures between U.S. companies and various Chinese cities. China/Tech has focused on developing such industrial technologies as microprocessors and robotics for applications ranging from automated weaving to poultry processing.

Although an initial agreement was signed in 1984, China/Tech did not begin operation until earlier this year. It is a for-profit organization that operates on fees from its clients—that is, the U.S. companies that supply the technology and the Chinese cities where the new industries will be based.

Although China/Tech is headquartered on the Georgia Tech campus in Atlanta, the school is staying at arm's length from the partnership's business dealings. Georgia Tech's role is one of "guidance" to the American half of the partnership, an organization called Technology Exchange Corp. (TEC), says TEC president Charles Langford. TEC's counterpart is the Technology Clearinghouse of China (TCC), a government agency that acts under the guidance of the China Association for Science and Technology, the country's largest scientific professional organization. TCC has designated China/Tech its sole U.S. representative, making Georgia Tech a major conduit between American and Chinese technologists.

With its connection to both U.S. and Chinese cultures, China/Tech hopes to guide companies past common pitfalls in U.S.-China business relationships, such as striking a "deal" with Chinese officials who are later discovered to lack the necessary authority. Pricing is another difficult issue. The Chinese, says Langford, do not feel they should compensate Westerners for the accumulated knowledge that has made a technology possible; rather, they wish to pay only for the much lower cost of applying that knowledge to build a particular product. Such a clash is presently hindering efforts to market U.S.-made computers in China.

China/Tech plans to provide companies with a variety of services. It might advise, for example, whether the company should go into China on a joint-venture basis or simply sell products there. It could also help conduct market studies, prepare business plans, and guide the company through the systems of government approvals, licensing, taxes, and royalties that the Chinese have recently set up to deal with foreign ventures.

In one joint venture already being set up through China/Tech, a U.S. computer company will produce video display terminals in Tianjin, about 70 miles southeast of Beijing; the factory will be owned half by the Chinese and half by the Americans. Another venture will build advanced poultry-processing plants in two cities—Shenzhen, near Hong Kong, and Nantong, 65 miles northwest of Shanghai—at the cost of about $50 million each. (It will probably be some time before the Chinese, accustomed to eating farm-bred fowl, develop a taste for chickens raised in processing plants. In the meantime, the chickens will be exported to other countries in the Pacific Basin.)

China/Tech will also set up trade shows and conferences. For example, a meeting on telecommunications in October cosponsored by BellSouth drew 40–50 American companies to Beijing, making it one of the largest industry meetings ever held in China. These firms are no doubt eager to take part in building the country's phone system, which is believed to represent a market in the billions of dollars if the country goes ahead with an attempt at Western-scale industrialization. □

—Henry McDonald

New ceramic makes better cutting tool

New super-tough ceramic tools may soon produce a quantum leap in productivity for the metal-cutting industry. The faster cutting speeds made possible by these tools are reducing machining time and thereby slashing costs, despite higher tool prices.

Silicon nitride is the most promising of these hard ceramics; the latest silicon nitride cutting tools, about the size of a thumbnail, can machine cast iron at speeds as high as 5000 feet per minute (fpm), reports Thomas Smith, director of GTE's Ceramics and Metallurgy Technical Center (Waltham, Mass.). That represents a fivefold increase over the cutting speeds possible with conventional carbide coatings. Even higher cutting speeds—up to 7000 fpm—have been reported in recent tests on cast iron by Metcut Research Associates (Cincinnati).

Previous ceramic cutting tools, generally made of aluminum oxide (alumina), have failed to gain widespread acceptance in the metalworking industry. The mechanical shock and thermal stress generated during high-speed machining causes premature failure in these materials. Silicon nitride, on the other hand, shows longer tool life at speeds previously not thought possible, reports Robert Carlton, technical supervisor at Metcut.

Silicon nitride's high strength, good wear resistance, and low coefficient of friction—even at high temperatures—have been known for some time. But until recently, it has not been economical to process the material into useful shapes. The basic problem has been that when silicon nitride powder is hot-pressed, the result is a porous, low-density ceramic. Making a dense material that will not fracture under the

Letting the chips fly: A silicon nitride tool machines the superalloy Inconel 718 many times faster than possible with carbide tools.

stresses of high-speed machining has required introduction of an additive—typically, magnesium oxide. This process was expensive and time-consuming, however, and worked only for simple shapes.

Researchers have recently discovered that blending alumina with silicon nitride yields a material with the same crystal structure—and thus the same hardness—as silicon nitride, but which can be formed to maximum density and strength without the need for simultaneously applying pressure. And that, says Carlton, means that conventional powder metallurgy techniques can be used to process the ceramic, opening the door to lower manufacturing costs.

A number of silicon nitride-based materials have recently appeared on the market under various trade names; the essential differences between them are the additives and alloying agents they contain. Sialon, developed by Britain's Lucas Syalon Ltd. for jet-engine components, derives its name from its chemical makeup: silicon, aluminum, oxygen, and nitrogen. The material is being marketed in the United States by Kennemetal (Latrobe, Pa.) as Kyon 2000; machine tools made of Kyon 2000 reportedly combine the hardness of ceramics with a resistance to breakage approaching that of the coated carbides.

GTE's formulation, called Quantum 5000, is a composite of silicon nitride and titanium carbide. GTE has initially focused on the development of a tool material that could machine cast iron at high speeds. But by modifying the microstructure and using various additives, developers can tailor the properties of the ceramic for machining other metals. The greatest challenge is steel, says Thomas Buljan, who heads GTE's research on wear-resistant materials. At high temperatures, steel tends to react with the ceramic, rapidly wearing out the tool.

Silicon nitride is expected to find wide use for machining the new nickel-based superalloys used in the aerospace industry. Superalloys are notorious for making short work of conventional cutting tools; even at the relatively slow machining speed of 100 fpm, a carbide tool lasts only about 20 minutes. But tests by Kennemetal on Inconel 901, an extremely tough and abrasive superalloy used for jet-engine parts, indicate that Kyon 2000 will survive twice as long as carbide at 100 fpm and 15 times as long at 1000 fpm.

Most important, silicon nitride tools have led to productivity gains on the shop floor. When Garrett Turbine Engine (Phoenix) switched from carbide to silicon nitride tools, the time needed to machine Inconel castings dropped by 90%. Even though the ceramic tools cost three times as much as carbides, the overall machining cost was trimmed by 84%. Moreover, the ceramic cutters produced a better surface finish, according to Garrett.

Ceramic cutting tools have captured 7% of the Japanese machine-tool market, in contrast with only 2% in the U.S. market. This difference stems largely from Japan's younger machine-tool population; more systems there are capable of handling the higher cutting speeds at which ceramics excel. But as newer machines are installed in the U.S., ceramic tools—and silicon nitride in particular—should play an increasingly important role. □ ***—Ernest Raia***

Plastic cars hit the road

It may not show on the surface yet, but synthetic materials are steadily edging their way onto cars, taking over body areas that were once the exclusive domain of steel. There's a plastic hood and rear hatch on the new Ford Aerostar minivan, a plastic roof and rear doors on the Cadillac Fleetwood 75 limousine, and plastic tailgates on

Oldsmobile and Buick full-size station wagons. The new Ford Taurus and Mercury Sable sport all-plastic front ends—including grill, headlamps, and bumper—with no steel support underneath. The pioneering Pontiac Fiero goes even farther, with an entirely plastic exterior. And progress should be steady throughout this decade as plastic parts proven on one car are extended to other models, according to Irvin E. Poston, manager of composite applications at the General Motors technical center (Warren, Mich.)

The contest between materials began to heat up during the fuel shortages of the '70s, when plastic-bodied cars seemed a sensible way to reduce car weight and hence boost mileage. But plastic's advantages extend beyond fuel economy. For starters, synthetic-skinned autos solve the nagging problem of rust, and they resist denting. Also, plastic gives automakers the flexibility to style and differentiate cars for a market that's getting finicky and fragmented.

From the automaker's standpoint, plastic brings improved manufacturing efficiency. Sheet-metal presses excel at turning out large numbers of stampings rapidly; thus, metal panels must be stockpiled until the assembly line is ready for them. Once a car has been tooled for steel, moreover, the design is locked in for a long production run, since the carmaker must produce the panels in high enough volume to get an adequate return on the investment.

Plastic molding, on the other hand, "lends itself to on-the-line operation balanced to the assembly rate," says Poston. Plastic presses can operate alongside a final assembly line, turning out fenders, doors, hoods and other panels as needed; it's the ultimate in just-in-time inventory control. Also, because fewer tools are required to make a plastic part than the same piece in metal, machinery costs are much lower. Therefore, says Poston, it becomes economical to change styles at shorter intervals than when dealing with metal. Moreover, plastic offers greater design possibilities because it can be molded into an endless array of shapes, many of which are not possible with metal stampings.

One obstacle to wider use of synthetics in cars, however, is inertia: Most automotive engineers have been trained in the properties of metals. Another barrier lies in the vast capital investment car companies have already made in existing plants. "Plastic is handled differently, processed differently, painted differently, and assembled differently" from metal, says Poston. In the place of spot-welding stations and rustproofing dip tanks will be special handling and forming tools.

In fact, the move to a predominantly plastic automobile will require building an entirely new factory or at least gutting an existing one. Thus, greater use of plastic in car bodies will probably await not only the design of new cars but also the retirement of existing steelworking equipment. Production of the Pontiac Fiero, for example, required GM to "completely redo" the plant where cars are assembled and painted, according to Poston.

But the coming generation of plastic-intensive cars may make the Fiero look primitive. The Fiero uses an all-steel body—a "space frame"—to support what amounts to a plastic shell. Poston says the Fiero space frame is assembled much like a conventional unibody automobile, with the combination of all the inner and outer body panels forming a structural whole without the need for a separate supporting frame. Future car programs—like GM's Saturn, Ford's Alpha, and Chrysler's Liberty—will likely move away from the unibody concept. These cars probably will consist instead of a structural chassis and a separate plastic cabin, says Douglas A. Nutter, manager of the Exterior Body Program at General Electric's plastics operations (Pittsfield, Mass.). Thus the manufacturer will gain the ability to change a body style easily for design variety without having to alter the more costly structural and power-train systems.

Plastic gives automakers the flexibility to style and differentiate cars for a market that's getting finicky and fragmented.

Still, "there are some technological hurdles to be overcome" before plastic becomes more pervasive on car bodies, says GM's Poston. For example, changes are needed in plastic formulation and tooling to make the material cure more quickly and uniformly, without the internal stresses or thickness variations that cause distortions or mar the finish. Indeed, Cadillac attempted a plastic hood on its limousine, but was forced to return to steel to obtain an acceptable finish.

Beyond the body, plastic is making other automotive inroads. "Every car company is looking at plastics for engines and structural parts," says James J. Kolb, automotive sales and development manager with the polyurethane division of Mobay Chemical (Pittsburgh). Already pointing the way are hidden components like plastic/fiberglass composite leaf springs in Chevrolet's Corvette, composite drive shafts in some Ford Econoline vans, and a plastic gas tank in the new Ford Aerostar.

A plastic engine is already popular in the endurance racing circuit of the International Motor Sports Association. The four-cylinder engine, built by Polimotor Research (Fairlawn, N.J.), is about 63% plastic by weight. The engine block is reinforced with graphite, and many internal moving components are molded from Torlon, a high-strength thermoplastic supplied by Amoco Chemicals (Chicago). Metal is retained for valves, piston heads, and other parts in direct contact with combustion. Polimotor president Matthew Holtzberg expects automakers to commit to plastic engine parts within a year, probably first for nonmoving parts, such as valve covers and oil pans.

Plastic parts decrease noise, vibration, friction, and wear, says Amoco's Terry A. Lappin, manager of engineering resins. Plastic also makes an engine lighter and, consequently, subject to less stress from the vibrating and rotating machinery. This makes it possible to use plastic, rather than a stronger metal, for the engine block and other parts that hold the engine in place. The overall weight reduction, in turn, permits a lighter suspension and chassis. In a sense, then, a plastic "seed" could propagate throughout the car. □

—*Jeffrey Zygmont*

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TECHSTARTS

Repligen:
BIOTECHNOLOGY TALENT FOR HIRE

Whereas most biotechnology start-ups harbor dreams of turning into manufacturers, Repligen intends to remain a think tank, hiring out its expertise to established companies. Clients run the gamut from Gillette (for which Repligen is creating a new antiperspirant) to relative newcomers like pharmaceutical biotech firm Centocor (with which it is jointly developing proteins for use in diagnostic testing). Although one of the company's first completed projects was producing recombinant Protein A, a substance used to help treat immune-system disorders, Repligen plans to limit the number of contracts it accepts in the healthcare field, concentrating instead on products with shorter time-to-market cycles. Other current research includes projects to develop pesticides, food additives, and enzymes for use in papermaking.

Financing: $12 million in venture capital financing from investors including the Rothschild Group, Doan Resources, Gillette, Nordic Investors, the Abingworth Group, and Hambrecht & Quist.

Management: Founders Alexander Rich and Paul R. Schimmel, professors at MIT, head the company's scientific advisory council. Steven James Lee, president and CEO, was president of Venture Management Advisors, Nordic American's venture capital operation. Thomas Fraser, executive VP and chief technical officer, was director of genetic engineering at Upjohn.

Location: 101 Binney St., Cambridge, MA 02142, (617) 354-1910.

Founded: March 1981.

RICK FRIEDMAN

The fruits of Repligen's R&D range from proteins for pharmaceuticals to wood-digesting enzymes for papermaking, says president Steven Lee.

Multiflow Computer:
ENTERING THE MINI-SUPERCOMPUTER MARKET

New designs for very fast computers aimed at the scientific and engineering market—often called mini-supercomputers—have been appearing in droves recently. One of the latest, from Multiflow, automatically compresses software written for conventional computers into a format (called "very long instruction word" code) that directs the machine to process portions of the program simultaneously. With the computer still under development, however, Multiflow has missed being in the first wave of companies—which includes start-ups Sequent, Flexible, Alliant, and Convex—in an increasingly crowded market. Multiflow's target market will be corporate R&D groups that currently use minicomputers from makers such as Digital Equipment and Data General.

Financing: $7 million in venture capital financing from investors that include Alan Patricof & Co., Fairfield Venture Partners, Bessemer Ventures, Paine Webber Venture, Apollo Computer, and General Electric Capital Corp.

Management: The company's three founders—executive VP Joseph A. Fisher, VP of engineering John J. O'Donnell, and VP of software development John C. Ruttenbert—were members of a Yale Computer research team. Donald E. Eckdahl, president and CEO, was senior VP at NCR, where he was in charge of engineering and manufacturing.

Location: 175 N. Main St., Branford, CT 06405, (203) 488-6090.

Founded: April 1984.

Opus Systems:
A HIGH-POWERED ENGINE IN A MICROCOMPUTER

A powerful engineering workstation with a PC pricetag is the combination that thousands of potential users of computer-aided design, manufacturing, and engineering (CAD/CAM/CAE) systems are eagerly awaiting. But it's no easy task for workstation vendors—equally eager to reach a new base of customers—to adapt their complex software to simplistic PCs. One way to ease the transition is with extra horsepower from an additional circuit board like the Personal Mainframe from Opus. Designed for IBM PC/ATs or PC/XTs and look-alikes, the board includes a 32-bit microprocessor (running the Unix operating system), a numeric processor, and extra memory. Opus already has contracts with Auto-trol Technology, a maker of CAD/CAM workstations, and Numetrix, a maker of workstations for production scheduling. So far, competition is limited to start-ups such as Perception Technology and to makers of somewhat similar "single-board computers" such as National Semiconductor and Goodspeed Systems.

Financing: Seed capital was provided by the founders.

Management: Ted Atlee, president, directed sales for computer maker Onyx Systems. Jon Lundell, chairman, is founder and principal of Cogent Associates, an engineering consulting firm. Craig Forney, VP of product support, was a founder of Plexus Computers and, previously, of Onyx Systems.

Location: 20863 Stevens Creek Blvd., Bldg. 4, Cupertino, CA 95014, (408) 446-2110.

Founded: March 1984.

FIBER OPTICS SUSTAINS HIGH GROWTH

Networks expand as competition heats up

Paced by productivity gains and falling costs, sales of fiber optic cables have been increasing rapidly. Such cables consist of extremely pure, thin strands of glass through which voice, data, facsimile, and video transmissions are sent over beams of laser light. Compared with the typical pair of longline copper telephone wires, an optical cable is lighter, takes up much less space, and can carry 800 times as many phone calls. Fiber capacity should quadruple within three years as faster single-mode fibers come on line. In addition, fiber links are unaffected by external noise and electromagnetic interference, and the signals they carry are not easy to intercept.

The competitive atmosphere after the divestiture of AT&T has also promoted the current expansion of national and regional fiber optic networks by AT&T, its long-distance competitors, and the independent Bell companies. As more fiber optics come on line, installation costs have been decreasing. According to AT&T, the cost of fiber optics now being installed will be less than $1 per circuit-mile when fully utilized, versus an average of $10 for copper longlines.

As a result of these factors, U.S. revenues for optical fibers alone have doubled annually over the past seven years, and sales in the total fiber optics market (glass fibers, cables, lasers, connectors, splicers, and other equipment) are approaching $1 billion. By 1990, the brokerage firm of Laidlaw, Adams & Peck (New York) expects the market to reach $2.3 billion.

The main users of fiber optic systems are AT&T and the other longline telephone companies. Although there may be a short-term slowdown in the planned expansion of long-distance systems to avoid a glut in capacity, other market segments are beginning to grow. These include overseas communications (by 1988, AT&T is planning to complement the transatlantic 4200-voice-channel coaxial cable laid in 1983 with optical cables carrying 40,000 channels), military communications, local-area networks interconnecting computers and peripheral equipment, local telephone company interoffice trunking, and process control networks in factory automation systems.

by Marie-Helene du Chastel

Optical cable manufacturing is dominated by Corning Glass, AT&T, ITT, and Japan's Sumitomo. Fiber operations account for a significant proportion of the revenues of Corning and a group of smaller firms that provide fiber optic component products and systems-integration services for specialty markets. Three such companies that have enjoyed rapid growth are Fibronics International (Hyannis, Mass.), Artel Communications (Worcester, Mass.), and Spectran (Sturbridge, Mass.).

Fibronics (FBRX: OTC) has almost tripled its sales and net income since going public in 1983. The company targets mainly the local-area network market segment, for which it designs and services fiber optic systems and produces such components as high-performance optical fiber, optical cable, and specialized electro-optic devices. Major products include fiber optic modems and high-speed voice/data distribution networks that link mainframe computers with data terminals, printers, and telephone systems. Fibronics recently announced several agreements under which it will act as original equipment manufacturer for ITT Courier Systems, GTE Midwestern Group, and AT&T. These long-term arrangements strengthen the company's profit-making potential.

In fiscal 1984, Fibronics reported sales of $13 million, a net income of $1 million, and 35¢ earnings per share, compared with estimated 1985 sales of $25 million, profits of $2.3 million, and 45¢ earnings per share.

Artel (AXXX: OTC) makes fiber optic systems (modems, interfaces, and other add-ons) for sending computer graphics, data, video, and audio signals. About 40% of Artel's sales in 1984 were from military command and control systems; other markets include computer-aided design and manufacturing (CAD/CAM), corporate teleconferencing, and satellite-to-earth station transmissions. The company recently introduced a general-purpose fiber optic local-area network—the first of its kind in the industry—that will provide high-speed communications between computers and workstations. This product should facilitate Artel's penetration of CAD/CAM markets in the aerospace and automobile industries, which are particularly important for the firm's future growth.

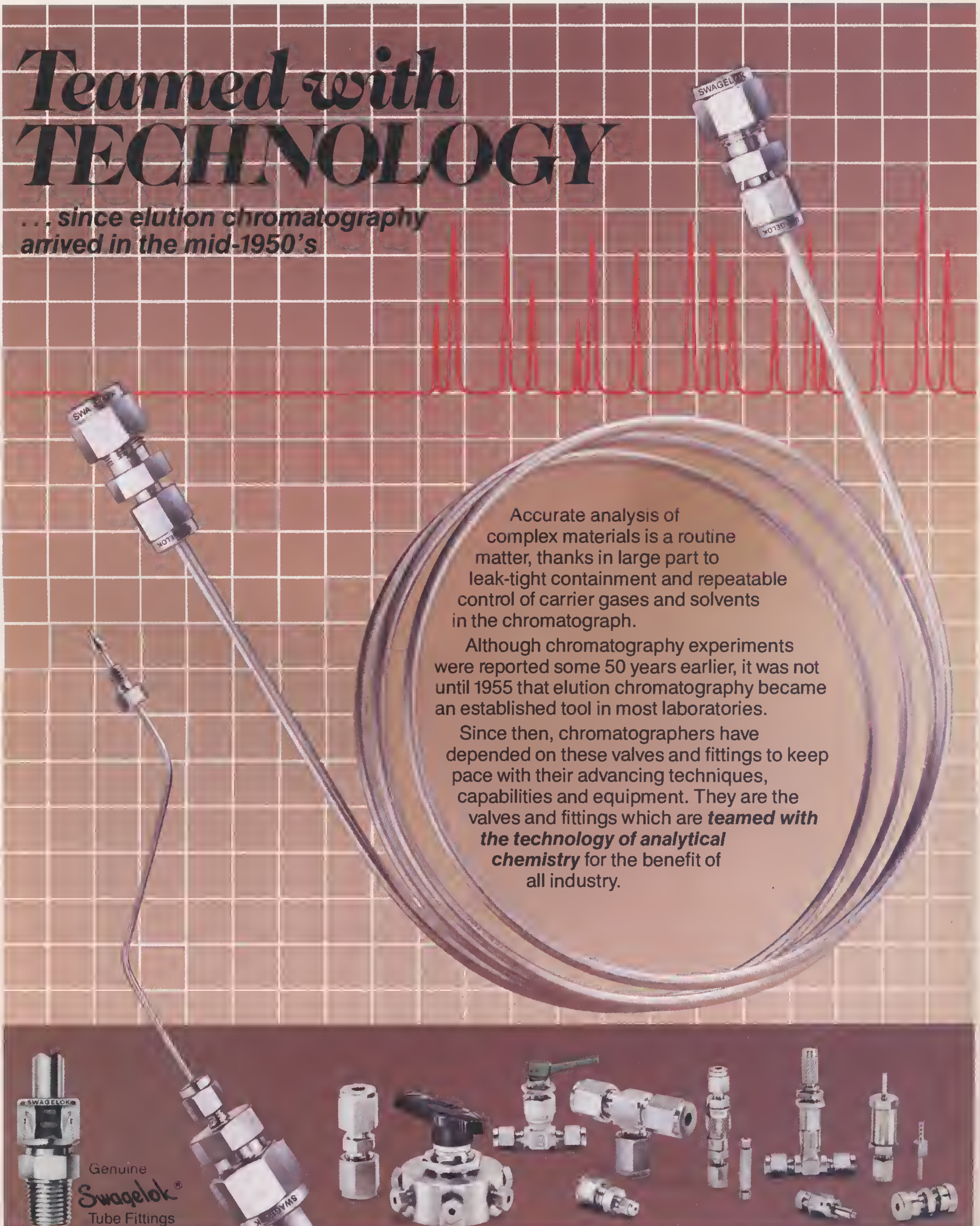
Fiscal 1984 sales were $4.2 million, with earnings of $600,000 or 18¢ per share. In 1985, earnings should be $700,000, based on revenues of $7 million and 20¢ earnings per share. The relatively slight rise in profits is largely because Artel is plowing back funds for research and development on local-area networks.

Spectran (SPTR: OTC), a licensee of Corning Glass Works and AT&T, manufactures a variety of specialty fibers. The company's long-distance fibers are used for carrying telecommunications signals and for controlling power distribution in high-voltage electrical power networks. Its short-distance products are used in computers and local-area networks. Spectran also makes radiation-resistant fibers for military use, fibers capable of transmitting ultraviolet light for process control instruments, and fibers for fire detection and medical applications.

The license from Corning sets limits on the amount of fiber that Spectran can manufacture and sell. However, last August, Spectran acquired a subsidiary of Southern New England Telephone, whose patent rights do not contain such restrictions.

Estimated 1985 sales should reach $15 million, with net income at $2.5 million and 60¢ earnings per share, compared with 1984 sales of $6.4 million, profits of $600,000, and 15¢ earnings per share. □

Marie-Helene du Chastel is telecommunications research analyst at Laidlaw, Adams & Peck, a brokerage firm in New York.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Their solution was Personal Consultant, a new expert systems development software tool from Texas Instruments for TI or IBM® personal computers.

Designed to run on 512K-Class Personal Computers, Personal Consultant provided Westinghouse an eminently affordable new tool for the development of expert systems. Pessall and Schreurs were especially impressed with its ability to aid experts in developing the knowledge bases and prototyping programs which even first-time computer users could consult for expert advice.

"With Personal Consultant software," says Schreurs, "we found it far easier to teach our experts how to develop a system than teach a programmer to be an expert." In fact, the software's rapid expert system prototyping and simple debugging features enabled the two scientists to demonstrate three different expert systems in as many weeks. Schreurs produced one for training new salespeople and a second to guide repairs and maintenance for the Center's X-ray defractometer. Pessall's makes material recommendations for tubes and support plates in steam generators.

"Our development of expert systems isn't aimed at replacing experts," says Dr. Pessall. "Its purpose is to give them the time to extend their expertise while the expert systems handle consultations on well-established knowledge and methodology."

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